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A New Mathematical Model of Optimization Load Shedding in Distribution Systems to Achieve Strategic Objectives of Electricity Demand Side Management

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ABSTRACT

In the general case demand side management is programming that effect on power consumption pattern of customers. In power systems in the peak hours amount of peak load is increasing, so these systems near the critical point can be exploited. The major objective of power systems is to supply electricity to its customers. During emergency state of the power system, it may shed partial loads to ensure the power supply to important loads, as the last resort to maintain system integrity. Load shedding in bulk power system has been studied many years. In electric power systems heavy loading may lead to voltage instabilities or collapses or in the extreme to complete blackouts. In result event and phenomena which causes of outage have paid more attention. Load shedding is the one of the effective method that keeps reliability of power system in critical times and shortage of production. The lack of appropriate load shedding method in distribution systems led Most of researchers to investigate on this major. In this research proposed a mathematical model of optimization load shedding in old distribution systems and smart grid. The proposed method including all of constrains and specify optimized load for shedding. The model is a nonlinear programming that the GAMS software has been solved. Output of software is chosen load for shedding to optimize cost of distribution systems. Objective function selects the least value of loads for shedding. An optimal load shedding strategy for power systems with optimum location and quantity of load to be shed is presented in this paper. The problem of load shedding for avoiding the existence of voltage instability in power systems is taken as a remedial action during emergency state in transmission and distribution sector. Optimum location of loads to be shed is found together with their optimum required quantity.

Introduction

Because of extent of power transmission networks, there is always the possibility that these networks due to various errors face emergency conditions .In this situation if appropriate corrective action is not taken on the network this network will unstable and practically blackouts will occur. One of the causes of instability in power system is the overload in power system. Overload in transmission lines will be led out of other lines. So we should behind this problem. Stability of power systems and prevent excessive reduction of frequency and voltage are the major issues that experts have always considered them, because instability of equipment may lead to fragmentation of the network and the reduction of voltage will collapse voltage in network and cause long blackouts and economic losses. So therefore we should attempt to prevent these issues, even if this is done with load shedding and temporary outages of some consumers. In this emergency, usually of options such as load shedding (cutting electricity of some consumers) and displacement in the production and distribution of electric power plants and distribution centers can be used to control the power transmission network.

Literature Review

Methods of Load Shedding

In studies such as Anderson (1992), Hsu (2005) and Hooshmand (2012) In general, the methods of frequency Load Shedding divided into two main categories static Load Shedding and dynamic Load Shedding. Static load shedding has fixed frequency settings and fixed amount for all stages. The Load Shedding due to changes in system load has steady performance and therefore does not have the necessary flexibility for the proper functioning. One of the solutions to the problems of static load shedding program is the dynamic load shedding. Amraee et al (2006) expressed instability of voltage due to out of generator from line or overload. When this occurs, the power of reactive will change greatly and if not restored quickly may cause blackouts. Technology of Load Shedding via voltage to avoid voltage instability is used. Computational intelligence techniques are techniques that mimic human intelligence. These techniques include neural networks, adaptive neuro-fuzzy inference systems, fuzzy logic control, genetic algorithms, particle swarm optimization; these techniques can solve easily nonlinear and multi-objective problems in power systems so that these issues are not solved with conventional methods (Haidar et al., 2008; Haidar et al., 2010). Using Control systems is one of the best ways that enables high-speed has optimal Load Shedding. Most of intelligent ways that they can help to optimize the time and Load Shedding include expert systems, artificial neural networks. Artificial neural network method for adaptive capacity and high speed is the most effective method. Ultra-high speed of neural networks also provides optimal load shedding at transient times (Hsu, 2005). An adaptive neuro-fuzzy inference system technique is combination of artificial neural networks and fuzzy logic control. This technique is capable of learning artificial neural networks and fuzzy control system using fuzzy logic. Using this method in problems of power systems has grown substantially. Some of these issues such as the possible voltage, potential power, dynamic security assessment, load forecasting in short-term, stability the power of system, fault of lines, and quality of power are used (Laghari et al, 2013). One of the methods of optimizing the mathematical model is non-linear programming techniques. In Power transmission systems due to the fact that these systems have non-linear equations, models are generally nonlinear (Azar et al, 2008).

The value of lost load (VOLL)

Because there is a no market for the exchange of power outages, so a market price that the final cost to show off at any minute is not available.

Nooij et al (2007) investigated the Security of electricity supply in the Netherlands using a production function approach to calculate the lost production and active search for their families. They assume that a power failure loses production units and households lose their leisure time. Then by value of each of these factors estimate the cost of power outages. Their results show that a kWh of electricity is not supplied on average have 6.8 euro value. Chen and Vella (1994) investigated economic costs caused by the lack of electricity for industrial sectors in Taiwan. They used Leon tief input-output framework for direct effects. It is noteworthy that in this study the valuation of lost production value is estimated electricity supply security. Moeltner et al (2002) investigated costs of outages for commercial and industrial subscribers of American company. They also used random coefficient model to eliminate heterogeneity and zero responses, allowing that parameters change among respondents. Their results show that the hypothesis of parameter stability and homogeneity strongly rejected.

Smart Grid

Smart Grid is a power system that mostly used in computer and communications technology to achieve two main goals. One of the main objectives of providing consumer information energy consumption pattern and the next goal is to achieve high power system reliability and power quality, and improve system performance by reducing system loss and better use of scatter resources.

Distributed Generation (DG)

By increasing demand for electrical energy, need to installation of large-scale plants and power transmission lines will be increased, which both require a lot of time and cost. The use of distributed generation of electrical energy as one of the solutions to the problems introduced. These energy sources include wind turbines, solar cells, fuel cells, the simultaneous production of heat and power systems and other resources that install in distribution system. This type of production can be identified with the name of the distributed generation and its energy resources called distributed energy resources (Jadid et al, 2012).

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Modeling

In this study, a new method for optimal load shedding and restructuring of traditional distribution networks is proposed. The proposed method takes into account all the constraints. To express the objective function and constraints first notation are expressed.

Notation

X_i	Binary variable that determines load in bar I is interrupted or not. If 1 is meant to cut.
$VOLL_i$	The value of load lost in bar i
P_i^c	Active power of bar i
$P_{loss-line}$	Line power loss
$P_{loss-transformer}$	Transformer losses
LMP	Cost of losses
V_i	Voltage of bar i
$V^{\max}$	The maximum voltage of each bar
$V^{\min}$	The minimum voltage of each bar
S_B^{Line}	Power of each line
$S^{\max}$	Maximum power of each line
$S_i^{Transformer}$	Power transformers i
$S^{\max-\text{Transformer}}$	The maximum power of each transformer
V_k	Voltage of each bus bar
I_B	Flow of each line
S_i^G	The power of DG i
P_R	load cuted
P_{R0}	The load shedding
d	The error in load shedding
P_i^G	Real power of DG i
Q_i^G	Reactive power of DG i
S_i	Power of Bus bar
R_B	Resistance of each line
R_i	Resistance of transformer
I_R	real component of flow
I_X	imaginary component of flow
Q_i	The total consumption of reactive power at bar i
Q_{Li}	The power of Reactive transformer i
ϕ	Angle of power factor
$P_{loss,R}$	Losses due to the real part of flow

$P_{loss,X}$ Losses due to the imaginary part of flow

Proposed Model

The proposed model to remove the load on the network is presented as follow. The objective function and the constraints have been described as follow.

$$\min \quad objective=\sum_{i=1}^{n} X_i \times VOLL_i \times P_i^C + [P_{Loss-Line} + P_{Loss-Transformer}] \times LMP \qquad (1)$$

The proposed objective function includes minimizing cost subject to additional charges casualties lines and distribution transformer. Equation (1) indicates objective function.

$$V^{\min} \leq V_i \leq V^{\max} \qquad (2)$$

$$-S^{\max} \leq S_B^{Line} \leq S^{\max} \qquad (3)$$

$$-S^{\max-\text{Transformer}} \leq S_i^{Transformer} \leq S^{\max-\text{Transformer}} \qquad (4)$$

$$S_B^{Line} = V_k \times I_B^* \qquad (5)$$

$$S_i^{Transformer} = (S_i^G + (1-X_i) \times S_i^C) \qquad (6)$$

$$P_R = \sum_{i=1}^{n} X_i \times P_i^c \qquad (7)$$

$$(1-d) \times P_R \leq P_R \leq (1+d) \times P_R \qquad (8)$$

$$S_i^C = P_i^C + jQ_i^C \qquad (9)$$

$$S_i^G = P_i^G + jQ_i^G \qquad (10)$$

$$S_i = S_i^C + S_i^G \qquad (11)$$

$$P_{Loss-Line} = \sum_{B=1}^{m} R_B \times I_B^2 \qquad (12)$$

$$P_{Loss-Transformer} = \sum_{i=2}^{n} (1-X_i) \times R_i \times I_i^2 \qquad (13)$$

$$I_i = X_i \times \left(\frac{S_i}{V_i}\right)^* \qquad (14)$$

$$[\Delta V] = [BCBV][BIBC][I] = [DLF][I] \qquad (15)$$

The constraints of model describes as follow:
Equation (2) represents a constraint of bus bar voltage of distribution network. According to the above equation is known that after the removal of load, the voltage will set between the maximum and minimum bus bar. This is most important constraint among others because lack of this constraint caused the collapse of network. It is better that voltages change to per unit that all equipment under stress are equal, but in practice it is not possible and voltage will keep the in an acceptable range. Equation (3) represents a power in different lines. This is an imaginary power that with the letter of S is shown. This can include active power P and reactive power Q's. As we know, power transmission from lines and distribution networks is limited. Thus, due to the thermal tolerance lines, legal flow should not exceed the nominal value. Equation (4) shows the limit transmission of network transformers. The distribution network transformers equipment is worth. The life of this transformer is extremely low and may even cause errors and cut them in a state of overload. Current power in lines through the equation (5) is calculated. The Power of transformers through the equation (6) is calculated. This equation used a binary variable. Binary variable determines load in bar i is interrupted or not. In the case of DG in the bar, their power in transformers as well as in the

objective function will be calculated. The balance of Remove power in the distribution network in the equation (7) is established. Because in some cases it may be precisely this equality is not restored, the equation (8) instead of (7) was used in the original model. In order to precise modeling, for each of bus bars are considered separate power. The proposed model is also implemented in smart grid. Each of terms of production or consumption of active and reactive power is expressed in equations (9) and (10). Net Power of each bus bar is implemented as well as the equation (11). Casualties of lines and transformers of grid are calculated by equation (12) and (13). Teng (2003) used an efficient method for the calculation of load with the ability to solve very large networks. For calculation by this method equation (14) is used. Then, using equation (15) flow equations are expressed. It should be noted that voltage difference between each node voltage distribution and post with current directory can be expressed through matrices branch current to bus voltage and injection to branch current and distribution load flow.

Data of distribution networks

To simulate the load shedding figure 1 is used. All details are listed in Tables 1 and 2.

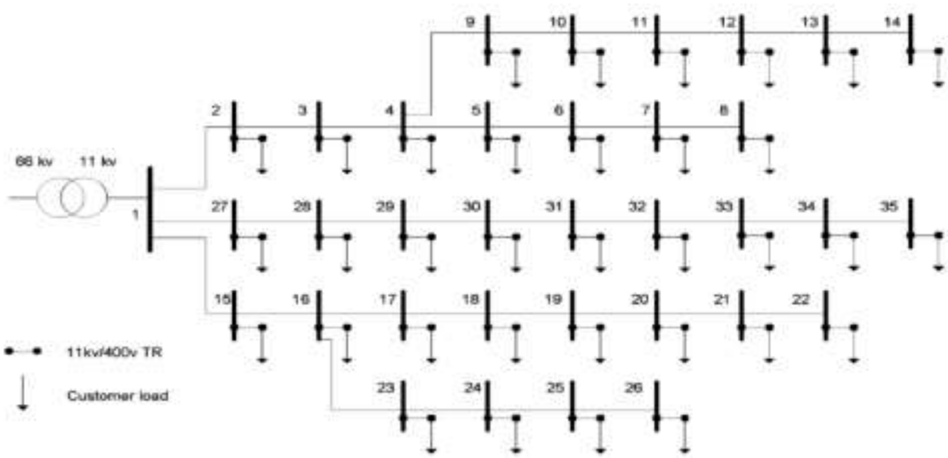

Figure 1: Example of distribution network

Distribution network that is fed by trans-kv 66/11 and has 35 bus bar that information is given in Table 1. This network has 34 lines that other information express in Table 2. This study attempted to simulate a real distribution network in zanjan city, according to the information that have restrictions on the output of Zanjan Regional Electric Company therefore necessary data and other factors such as the value of time lost, the cost of losses, the number of customers, power outages, etc., based on field research and use of Zanjan regional Electric Company of electricity and university professors have been extracted. Costs for uniformity and comparability of external research are expressed in terms of dollars.

Table 1: information of each bus in distribution network that has 35 bus bar

Bus bar transformer	peak of load		End load		R (p.u.)	X (p.u.)
	P(KW)	Q(KVar)	P(KW)	Q(KVar)		
2	19	11.7	8.0	2.6	0.71875	0.06
3	409.1	254.2	50.8	37.2	1.28	0.06
4	260.9	203	82.2	56.2	0.71875	0.06
5	547.7	243.3	37.7	30.2	0.71875	0.06
6	185.4	153.4	14.2	12.6	0.71875	0.06
7	260.1	146.1	19.7	15.6	1.839254	0.04
8	445.1	157.4	183.7	99.5	1.28	0.06
9	493.1	203	190.2	83.7	1.28	0.06
10	186.3	67.7	68.0	26.9	1.28	0.06
11	342.8	149.3	114.8	55.4	1.839254	0.04
12	319.8	113.1	93.2	24.2	1.839254	0.04
13	68.2	21.9	31.5	9.9	1.28	0.06
14	244.2	87	116.3	42.3	1.28	0.06
15	499.4	196.5	445.8	168.9	0.71875	0.06
16	717.5	406.1	439.6	212.2	0.71875	0.06
17	659.5	431.7	389.8	345.0	0.71875	0.06

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18	765.6	348.4	304.7	158.7	0.71875	0.06
19	873.5	551.9	306.2	214.9	0.71875	0.06
20	830.6	253	456.2	154.1	0.71875	0.06
21	988	280.5	410.2	119.5	0.71875	0.06
22	346.6	163	101.3	64.7	1.28	0.06
23	138.8	45.9	62.9	20.3	1.839254	0.04
24	183	41.2	55.7	11.1	1.839254	0.04
25	839.6	190.7	267.9	64.2	0.71875	0.06
26	13.9	4.3	5.1	1.2	0.71875	0.06
27	112.5	14	62.6	5.6	1.28	0.06
28	86.1	16.2	8.5	3.0	1.28	0.06
29	774.6	358.1	81.5	44.9	0.71875	0.06
30	461.1	175.8	53.1	11.2	0.71875	0.06
31	242.2	59.5	125.7	40.6	0.71875	0.06
32	48.1	0.1	66.3	3.0	1.839254	0.04
33	348.2	106.7	140.3	52.4	1.28	0.06
34	0.7	0.8	0.5	0.6	1.28	0.06
35	394.8	126.6	111.7	65.5	1.28	0.06
Total	13106	5582.1	4906.0	2257.8		

Table 2: information of each bus in distribution network that has 34 lines

Line		R	X	B
Until the end of the line	From the beginning of the line	(p.u.)	(p.u.)	(p.u.)
1	2	0.009686	0.015187	0.000184
2	3	0.006954	0.010904	0.000132
3	4	0.006209	0.009736	0.000118
4	5	0.011672	0.018303	0.000222
5	6	0.011672	0.018303	0.000222
6	7	0.003229	5.06E-03	6.15E-05
7	8	0.007699	0.012072	0.000147
4	9	0.003229	5.06E-03	6.15E-05
9	10	0.017136	0.02687	0.000326
10	11	0.009686	0.015187	0.000184
11	12	0.006954	0.010904	0.000132
12	13	0.006209	0.009736	0.000118
13	14	0.011672	0.018303	0.000222
1	15	0.040977	0.068543	0.000822
15	16	0.029802	0.04985	0.000598
16	17	0.010927	0.018278	0.000219
17	18	0.023593	0.039464	0.000473
18	19	0.007947	0.013293	0.000159
19	20	0.0226	0.037803	0.000543
20	21	0.00596	0.00997	0.00012
21	22	0.000993	0.001558	1.89E-05
16	23	0.004222	0.00662	8.04E-05
23	24	0.006209	0.009736	0.000118
24	25	0.006954	0.010904	0.000132
25	26	0.00447	0.00701	8.51E-05
1	27	0.009934	0.015577	0.000189
27	28	0.00298	0.004673	5.67E-05
28	29	0.009934	0.015577	0.000189
29	30	0.005464	0.008567	0.000104
30	31	0.011424	0.017913	0.000217
31	32	0.001987	0.003115	3.78E-05
32	33	0.006457	0.010125	0.000123
33	34	0.00298	0.004673	5.67E-05
34	35	0.00298	0.004673	5.67E-05

The advantages of this modeling

In mathematical modeling such as Azar (2008), Moazemi et al (2014) and Mustafa et al (1996) objective function includes active and reactive power, but with respect to these functions changes can be seen .In Azar survey (2008) the objective function includes penalty functions and constraints related to the objective function, range of power is considered. Moazemi et al (2014) have been conducted survey by using of artificial neural networks and objective function includes active and reactive power and the constraints related to the objective function include the range of operating voltage bus (bus bars) and constraints on power range, as well as in research Mostafa and Mansour (1996) objective function in addition to active and reactive power include priority in terms of cut lines optimally that used. The innovation of this research includes objective function that considers the line losses and losses in the distribution network's transformers. Another advantage is that the objective function includes value of time lost as a factor that can be removed in the final cost. In addition, the use of binary variable is another advantage for this objective function. In the case of supply electricity consumers through the power grid, distributed generation sources for support of energy will operate. In Smart distribution network restructuring, DG will be discussed, another important benefit of this modeling investigation the effect of DG on Load Shedding and final cost.

Results for the case of DG is not in orbit

The proposed mathematical model to optimize Load Shedding and minimizing the cost of electricity distribution system was solved by GAMS software. To test this model, sensitivity analysis with different loads is measured.

P Load shed= 460

d= 0.1

The results showed that Load in 2, 34 and 35 bus bar should be discontinued. The cost of system will be 516126.178 $.
The variable of D shows the error rate. In other words, sometimes the balance can not be specified for the cut of power, For this reason, it is possible to change the error rate for Load Shedding, as well as the costs of providing these changes must be provided to be analyzed.

Table 3: Impact of accuracy error on the cost of Load Shedding

Pload shed	450	450	450	450	450	450
d	0.15	0.10	0.05	0.01	0.005	0.001
cost	466431.092	498522.591	517205.278	785220.338	785220.338	843532.877
Which bus	35	26,35	32,35	2,11,28	2,11,28	2,13,26,33,34

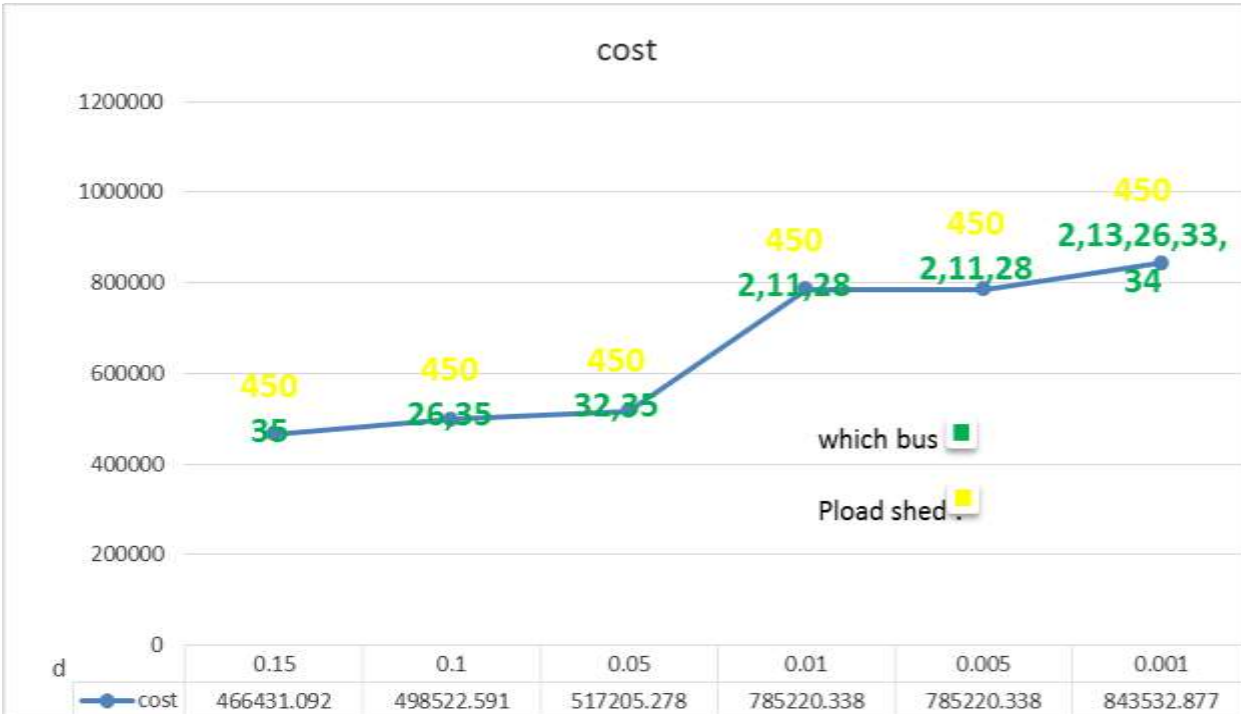

Figure 1: Impact of accuracy error on the cost of Load Shedding

Results for the case of DG is in orbit

P Load shed=460

d= 0.1

The results showed that Load in 2, 34 and 35 bus bar should be discontinued. The cost of system will be 515876.881 $.

Table 4: Impact of accuracy error on the cost of Load Shedding

Pload shed	450	450	450	450	450	450
d	0.01	0.05	0.01	0.005	0.001	0.00
cost	498273.508	516955.981	784971.777	784971.777	843283.846	843283.846
Which bus	26,35	32,35	2,11,28	2,11,28	2,13,26,33,34	2,13,26,33,34

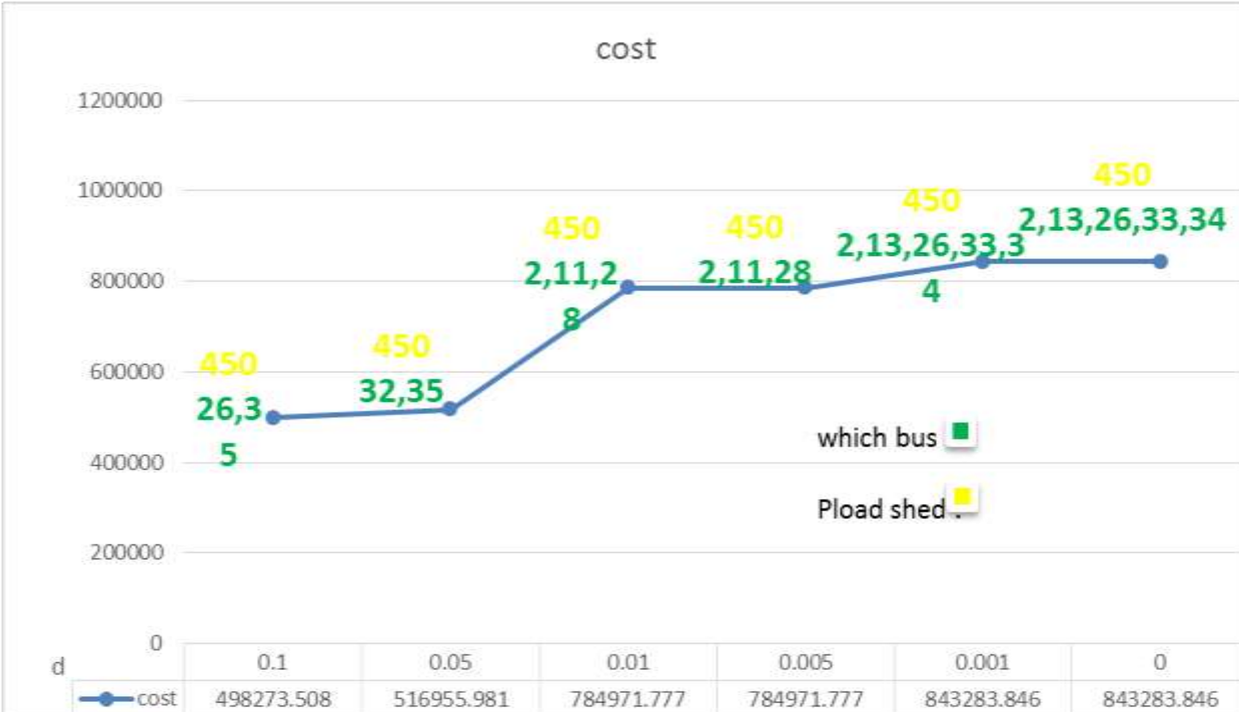

Figure 2: Impact of accuracy error on the cost of Load Shedding

According to result of GAMS software can be seen that in Load Shedding to equalize the distribution network, to increase accuracy and reduce error the cost of Load Shedding will increase.

Conclusion

One of the causes of instability the power system is overloaded. In power systems in the peak hour's amount of peak load is increasing, so these systems near the critical point can be exploited. The major objective of power systems is to supply electricity to its customers. During emergency state of the power system, it may shed partial loads to ensure the power supply to important loads, as the last resort to maintain system integrity. The lack of appropriate load shedding method in distribution systems led Most of researchers to investigate on this major. In this research proposed a mathematical model of optimization load shedding in old distribution systems and smart grid. The proposed method including all of constrains and specify optimized load for shedding. The model is a nonlinear programming that the GAMS software has been solved. Output of software is chosen load for shedding to optimize cost of distribution systems. Objective function selects the least value of loads for shedding. An optimal load shedding strategy for power systems with optimum location and quantity of load to be shed is presented in this paper. The problem of load shedding for avoiding the existence of voltage instability in power systems is taken as a remedial action during emergency state in transmission and distribution sector. The results showed that Load in 2, 34 and 35 bus bar should be discontinued. The cost of system will be 516126.178 $.The results show that with regard to DG, the cost of system will reduce. Also the amount of variable d in both cases show that in load shedding for the balance with increase of accuracy and reduce error, the cost of load shedding will increase.

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