Load Shedding Control Strategy in an Electric Distribution System

Cattareeya Suwanasri, Thanapong Suwanasri, and Nuttapong Prachuab

Abstract— *This paper proposed the load shedding control planning in a distribution network in order to ensure power system stability and availability during system disturbances. The load shedding criteria are based on demand capacity for loss of power situation and load importance for loss of frequency. Two configuration of distribution networks as tap-tie normally open and radial with emergency line are presented as examples. The results show that this load shedding criteria are effectively manage demands during power system instability occurs. This planning strategy helps to reduce time in actual operating conditions as well as the costs of power system interruption.*

Keywords— **Load shedding, load importance, distribution system, loss of power, loss of frequency, demand management.**

1. INTRODUCTION

In the power system, if there is an excessive load over available generation, the generators will begin slowing down as they attempt to carry the excess load. The system frequency will be getting lower than a nominal frequency [1]. The drop in frequency may endanger the generator itself. As system frequency decreases, the power output begins to fall off rapidly. Thus the situation has a cascading effect with a loss of frequency leading to a loss of power [2]. To prevent the collapse of the system, load shedding schemes should be performed in order to balance the load to the available generation and recover from the under frequency condition [3]. To increase the service quality to their customers, electric utilities established certain planning and operating rules, so that the power system is able to face at each instant the current uncertainties (N-1 criteria). These rules do not cover all contingencies and do not offer the guarantee that the power system is completely protected against major incidents. However, these incidents that take place in distribution, transmission or interconnection networks have important economic impacts within the regions or countries where they occur. A generalized blackout, at country scale, completely collapses it during the necessary time needed to restore the normal functioning of the power system, which can take up to several days [4].

In Thailand, there are three major electric utilities; Electricity Generating Authority of Thailand (EGAT) who has a function to control generation and transmission system; the Metropolitan Electricity Authority (MEA) who is taking care of the distribution system in Bangkok, Nonthaburi and Samutprakan; and the Provincial Electricity Authority (PEA) who is taking care of the distribution system in the rest areas. However, they have collaborated to implement a manual to support the overloading condition in the system because the reliability has always been the prime concern of the electric utilities.

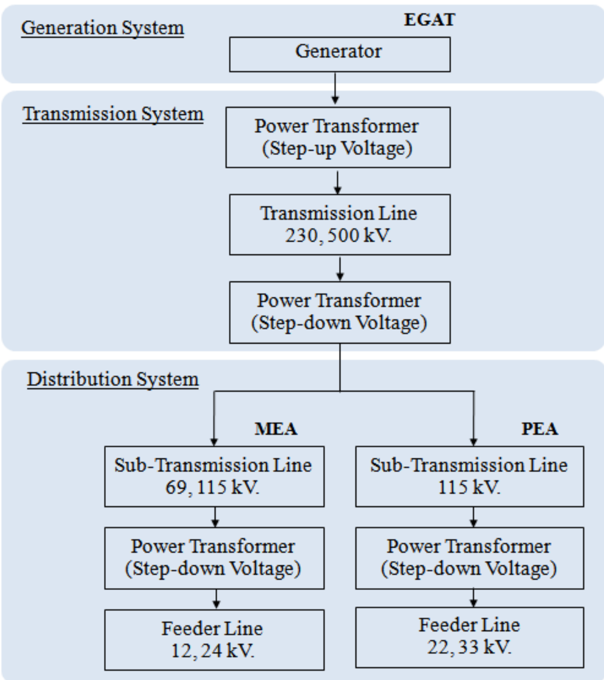

Fig.1. Transmission and Distribution Level in Thailand

In this paper, the load shedding control in the electric distribution system is proposed on the situations of a loss of power and a loss of frequency.

2. LOAD SHEDDING IN DISTRIBUTION SYSTEM

2.1 Load Shedding Control

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Nowadays, load shedding represents the final solution used to avoid voltage collapse, loss of synchronization, or overloads cascade on a wide area of power network after some resources have been exhausted while major consumers are powered during curative actions for these situations. Different techniques have been proposed to solve the load shedding problem in distribution network.

In [5], line ampacity violations and voltage drop violations at the load points are considering for load shedding in radial distribution systems. Ref. [6] explained load shedding in system with switch able capacitors and on-load tap changers. For voltage drop violations, the load point with violation, which does not have a switch able capacitor, will be shed. For current capacity violation at a component, a low priority load at a point beyond that component is shed. In [7], the effect of load-shedding on based on capacity and interrupting costs was investigated process when system instability occurs. In [8], an optimal load shedding strategy for power system with multiple DGs was presented. In [9-10], a genetic algorithm is employed to search for supply restoration and optimal load shedding in distribution networks.

In this paper, the load shedding control strategy based on load importance aspect as well as load capacity in the electric distribution system is proposed on the situations of a loss of frequency and a loss of power. Two configuration of distribution lines (tap-tie normally open, radial with emergency line) are presented as examples.

2.2.1 Load shedding on loss of power situation

The applications of overload shedding function are used to protect the cascading failure of power transformer(s). The consideration is involved with the maximum demand and the available capacity in each terminal substation. The available capacity can maintain the excess load up to 150% of rated for an hour. It is divided into two steps. In each step, loads are concerned about the outage area depends on demand capacity. The consideration of overload shedding scheme in both steps is the same, it is described as follows.

First priority considers a sub-transmission line that all connected load can be supplied by other neighboring sub-transmission lines. However, the capacity of neighboring line and power transformer(s) do not reach an overload situation as well.

Second priority considers a sub-transmission line that have the least load points still connected after almost load points were transferred to other neighboring sub-transmission lines in order to minimize the outage area.

2.2.2 Load shedding on loss of frequency situation

The applications of under-frequency relay are used to protect the generators. The functions of protective relay will depend on the strategy of each utility to control the system frequency. However, in this paper the procedure of load shedding on under-frequency relay is divided into five steps for 50 Hertz system frequency. In each step, load types are categorized by load importance. Load shedding from step 1 to step 5, the demands will be shed up to 50% of the total demand. Thereafter OFF 1 and OFF 2, the remaining demands will be shed each of 25% of the total demand until cover 100%. The load details are described as follows.

Step 1, 10% ± 1% of total demand is shed. The load type is mostly suburb residential areas.

Step 2, 10% ± 1% of total demand is shed. The load types are residential areas and some commercial areas.

Step 3, 10% ± 1% of total demand is shed. The load types are commercial areas and some small industrial areas.

Step 4, 10% ± 1% of total demand is shed. The load types are small industrial areas and some medium industrial areas.

Step 5, 10% ± 1% of total demand is shed. The load types are densely commercial areas, headquarter of commercial bank and medium industrial areas.

OFF 1, 25% of total demand is shed. The load types are industrial estates or large industrial areas, small hospitals and very important person household.

OFF 2, 25% of total demand is shed. The load types are Government areas, Palace area, medium and large hospitals, water pump stations and the internal electric system of substations.

Step OFF 1 and OFF 2 are the last shedding step. This highest priority feeders or loads will be disconnected only when the system nearly collapsed.

2.2 Distribution Systems

In a sample distribution system, the system is divided into two voltage levels as from the terminal substation to 115/69 kV sub-transmission line section and substation to 24/12 kV feeder line section.

Firstly, from the terminal substation to 115/69 kV sub-transmission line section, this refers to case of a power transformer failed, the demand will exceed remaining capacity. The sub-transmission line will be automatically shed via overload shedding function. There are two steps of overloading shedding function. Either step 1 and step 2 will automatically shed a specific line in four and two seconds, respectively; when the remaining demand still higher than the available capacity in order to protect the cascading effect on another power transformer(s).

Secondly, consider from substation to 24/12 kV feeder line, there is an application of underfrequency relay to protect the damage of generator due to prolonged operation at reduced frequency.

3. CASE STUDY AND ANALYSIS

3.1. Loss of Power Situation

For loss of power situation, the sample system, shown in Fig. 2, is at 115/69 kV level. The system consists of 8 terminal substations, 26 sub-transmission lines and 44 load points.

In Table I, the system data is described. For instance, two power transformers as rated of 100 MVA are connected at BUS-A while four power transformers as rated of 100 MVA are connected at BUS-D.

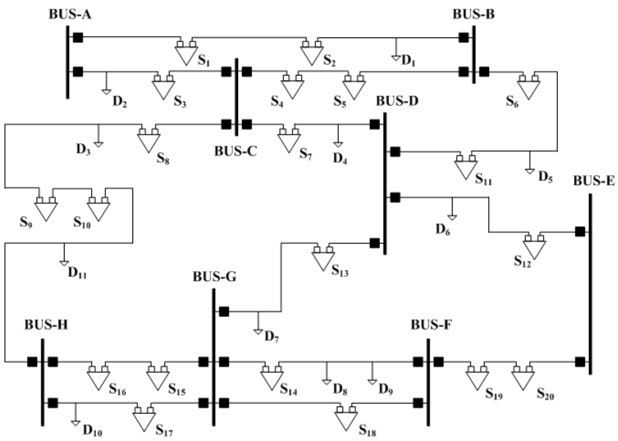

Fig.2. The 115/69 kV Power System Model

In Table II, the data of total 26 lines are given. For instance, line A1 is a connection between BUS-A to substation (S1) that demand of S1 as 70 MVA is connected. Similarly at line B1, the demands of S1, S2 and D1 as 45, 35 and 5 MVA are connected respectively.

Table 1. Total Capacity of Each Terminal Substation

Bus Name	Power Transformer (MVA)	Quantity	Total Capacity (MVA)
BUS-A	100	2	200
BUS-B	100	2	200
BUS-C	150	2	300
BUS-D	100	4	400
BUS-E	150	2	300
BUS-F	100	2	200
BUS-G	100	4	400
BUS-H	100	2	200

The criteria for loss of power situation are separated into two cases. Firstly, in case of the load on curtailed sub-transmission line cannot be transferred to a neighboring line; therefore, there is an outage on that disconnected line. Secondly, in case of the curtailed load can be transferred to a neighboring sub-transmission line; thus, the outage will not be occurred. The shedding situations are explained as following examples. At BUS-A, available capacity is 200 MVA as given in Table II, when there is a 100 MVA power transformer failed, the remaining capacity at BUS-A is 100 MVA while in that time the maximum demand is 160 MVA. By applying the regulation on 150% of the remaining capacity must be operated for an hour, thus the remaining power transformer supplies 150 MVA. This results to the minimum demand should be shed is 160 MVA-150 MVA = 10 MVA. However, this demand cannot be supplied by the neighboring terminal substations because they are operated at full capacity. Finally, this 70 MVA load connected at Line A1 must be totally shed. STEP 2 will be operated, if the remaining demand still excesses the capacity. At BUS-C, available capacity is 300 MVA, when a 150 MVA power transformer failed; the remaining capacity at BUS-C is 150 MVA while the maximum load is 255 MVA. The 150% of the remaining capacity must be operated, thus the remaining power transformer supplies 225 MVA. Therefore, the minimum demand should be shed is 30 MVA. In STEP 1, the 25 MVA load can be transferred and supplied by the neighboring terminal substation (BUS-D). However, the minimum demand as 30 MVA still excesses the curtailed demand as 25 MVA in STEP 1; therefore, STEP 2 operated. The 55 MVA in STEP 2 will outage because neighboring terminal substation operated at full capacity. This will be similarly to other cases in different buses to balance demand and supply during power outage situation. The shedding results are given in Table 3.

Table 2. Sub-transmission Line and Demand Data

Line	Detail	Load (MVA)	Line	Detail	Load (MVA)
A1	BUS-A to S1	S1 (70)	E1	BUS-E to S12	S12 (70)
A2	BUS-A to S3	S3 (65) D2 (25)	E2	BUS-E to S19	S19 (45) S20 (95)
B1	BUS-B to S1	S1 (45) S2 (35) D1 (5)	F1	BUS-F to S14	S14 (55) D8 (5) D9 (10)
B2	BUS-B to S5	S5 (35)	F2	BUS-F to S19	S19 (40)
B3	BUS-B to S6	S6 (40)	F3	BUS-F to S18	S18 (50)
C1	BUS-C to S3	S3 (55)	G1	BUS-G to S13	S13 (45) D7 (15)
C2	BUS-C to S5	S4 (40) S5 (30)	G2	BUS-G to S14	S14 (50)
C3	BUS-C to S10	S8 (20) S9 (35) S10 (40) D3 (10)	G3	BUS-G to S16	S15 (90) S16 (30)
C4	BUS-C to S7	S7 (25)	G4	BUS-G to S17	S17 (55)
D1	BUS-D to S7	S7 (35) D4 (10)	G5	BUS-G to S18	S18 (35)
D2	BUS-D to S6	S6 (45) S11 (70) D5 (15)	H1	BUS-H to S10	S10 (35) D11 (15)
D3	BUS-D to S12	S12 (65) D6 (30)	H2	BUS-H to S16	S16 (35)
D4	BUS-D to S13	S13 (50)	H3	BUS-H to S17	S17 (45) D10 (30)

3.2. Loss of Frequency Situation

For loss of frequency situation, the sample distribution system is at 24/12 kV as presented in Fig. 3. The system consists of 4 substations, 24 feeder lines and 35 load points which are divided into several types of areas such as residential area, commercial area and industrial area. Load details of each substation are given in Table IV.

For example, in Table IV at P-Substation, 6 feeders (P11 to P23) are connected. The major loads 15 MVA are connected to feeder P23, which is an internal electric system of P-Substation and palace area. The lowest priority load is defined as “1” and the highest priority load is defined as “7”.

When the demand highly exceeds the generation in power system, the loss of frequency situation occurs. The load shedding criteria are needed to be assigned in order to recover the system frequency. The priority load shedding based on load importance as described in section 2.2.2 must be performed. The feeder lines connected at P-Substation are then ranked against each other, the lowest priority feeders being targeted for load shedding first, the highest priority feeders are the last to be shed and typically first to have supply restored. The results are shown in Table V.

Table 3. Load Shedding Decision Caused by One Power Transformer Failed (* refers to outage occurs)

Remaining Capacity (MVA)	Maximum Bus Load (MVA)	150% of Remaining Capacity (MVA)	Minimum Load Curtailment (MVA)	Line Curtailment	Total Load Curtailment (MVA)
@ BUS-A 100	160	150	10	STEP 1 Line A1	70*
				STEP 2 Line A2	90
@ BUS-B 100	160	150	10	STEP 1 Line B2	35
				STEP 2 Line B3	40
@ BUS-C 150	255	225	30	STEP 1 Line C4	25
				STEP 2 Line C1	55*
@ BUS-D 300	320	450	-	STEP 1 Line D4	50
				STEP 2 Line D1	45
@ BUS-E 150	210	225	-	STEP 1 Line E1	70
				STEP 2 Line E2	140
@ BUS-F 100	160	150	10	STEP 1 Line F3	50
				STEP 2 Line F2	40
@ BUS-G 300	320	450	-	STEP 1 Line G1	60
				STEP 2 Line G5	35
@ BUS-H 100	160	150	10	STEP 1 Line H2	35
				STEP 2 Line H1	50

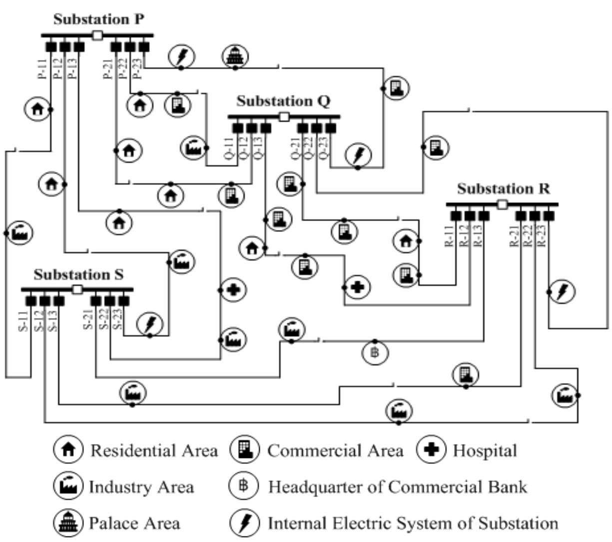

Fig.3. The 24/12 kV power system model

Table 4. Feeder Line and Demand Data

Sub.	Feeder	Description	MVA	Priority
P	P11	Residential Area	4	2
	P12	Suburb Residential Area	5	3
	P13	Residential Area	8	1
	P21	Suburb Residential Area	4	1
	P22	Commercial Area, Residential Area	6	2
	P23	Internal Electric System of P-Substation, Palace Area	15	7
Q	Q11	Small Industrial area	5	4
	Q12	Commercial Area, Residential Area	10	2
	Q13	Commercial Areas, Residential Area	9	3
	Q21	Commercial Areas	8	3
	Q22	Commercial Area	6	1
	Q23	Internal Electric System of Q-Substation, Commercial Area	12	7
R	R11	Densely Commercial Area, Residential Area	7	5
	R12	Small Hospital, Commercial Area	13	6
	R13	Headquarter of Commercial Bank	6	5
	R21	Densely Commercial Area	3	5
	R22	Medium Industrial Area	8	4
	R23	Internal Electric System of R-Substation	9	7
S	S11	Industrial Estate	11	6
	S12	Industrial Estate	15	6
	S13	Medium Industrial Area	4	5
	S21	Large Industrial Area	8	4
	S22	Small Hospital, Medium Industrial Area	10	6
	S23	Internal Electric System of S-Substation, Medium Industrial Area	14	7

Table V: Decision for Under-frequency Situation

Sub.	Step UF Relay					OFF1	OFF2
	1 49.0 Hz	2 48.8 Hz	3 48.6 Hz	4 48.3 Hz	5 47.9 Hz		
P	P13,P21	P11,P22	P12	-	-	-	P23
Q	Q22	Q12	Q13,Q21	Q11	-	-	Q23
R	-	-	-	R22	R11,R13, R21	R12	R23
S	-	-	-	S21	S13	S11,S12, S22	S23

In this case, the total demand in the system is 200 MVA. In STEP 1, when the system frequency decreases to 49.0 Hz, the 9-11% of total demand (18-22 MVA) must be shed, thus the residential loads (P13 and P21 feeder line) as the lowest priority are disconnected. If the system frequency still reduces to 48.8 Hz, STEP 2 must be operated. The next 9-11% of total demand must be shed, thus the second lowest priority in residential and commercial loads (P11 and P22 feeder line) are disconnected. If the system frequency cannot be recovered, the next steps will be subsequently operated. The highest priority loads as internal electric system of substation is the last step (OFF 2) to be shed.

4. CONCLUSION

The load shedding control strategy based on demand capacity and load importance in a distribution system is proposed in this paper. The tap-tie normally open configuration is presented for loss of power disturbance. The demand capacity aspect is applied to manage load shedding in this situation. The sub-transmission line that all connected load can be supplied by other neighboring terminal substations is firstly curtailed. Otherwise, the sub-transmission line, that the least load point(s) is connected, will be curtailed in order to minimize the outage area. Similarly, the radial with emergency line configuration is presented for loss of frequency disturbance. The load importance aspect is applied for this situation. The highest priority feeder is the last to be shed and normally the first to be restored. This planning strategy can effectively reduce operating time and interrupting costs during disturbance.

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