Impact Study of a Generation Rich Island and Development of Auto Load Shedding Scheme to Improve Service Reliability

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Abstract— **Abnormal conditions in a power system create fluctuations to electrical quantities such as voltage, frequency and current. Some of them may lead to fall of system frequency and sometimes extreme abnormality leads to system blackout. Planned and proper islanding may protect the system from complete blackout even in case of extreme abnormalities. Islanding operation not only helps stabilizing a faulted system but also supports power supplies to critical and important loads, in extreme emergency. But the islanding systems are weaker than integrated system so the stability of islands is the prime concern when an integrated system is disintegrated. In this paper different impacts on a generation rich island have been studied and a frequency based auto load shedding scheme has been developed for sudden load addition, generation outage and combined effect of both to the island. The developed scheme has been applied to Dhaka Island (the largest and generation rich island of Bangladesh Power System) to validate the effectiveness of the developed technique. Various types of abnormalities to the test system have been simulated and for the simulation purpose CYME PSAF (Power System Analysis Framework) has been used.**

Keywords— ***Auto load shedding, FS & FD Relay, Impact Study, Island, PSAF, ROCOF.***

I. INTRODUCTION

Since the industrial revolution the demand of the electricity for human beings has been increased a hundredfold and this dramatic increase has been occurred as a result of rising the living standards. Due to the increasing number of sophisticated consumers, requiring electric supply of high reliability, the need for power system stability study is inevitable. Throughout the world power grids have been experiencing blackouts in recent years [1-6], for example in Bangladesh (2007), Russia(2005), Italy (2003), Northeast USA-Canada(2003), Eastern Denmark and Southern Sweden(2003), Iran(2001,2002), Brazil (1999). It is clear from the recent blackouts today's power system operation requires effective control strategies and careful considerations of all sources of system instability.

When a power system blackout occurs due to extreme abnormality it causes huge losses to the utility as well as to its customer. According to [5]-[6], three recent blackouts occurred in BPS, generating a total system interruption of 110 GWh and a total loss of 15.9 million USD. When the frequency of a stable power system falls because of any physical disturbance; load shedding schemes then work as a very important and powerful tool to maintain system stability [7] which protect excessive frequency decline to protect the system from blackout by balancing load and generation. Emergency load shedding approaches to balance the load and generation of a power system to prevent the degradation of system frequency is an established practice all over the world. Widely used three main categories of load shedding schemes are: a) traditional b) semi-adaptive and c) adaptive [8]. Among these three schemes the traditional load shedding scheme is mostly used because of its simple operation and it does not require any sophisticated relay. A certain amount of load is being shed when the system frequency falls below a certain threshold [9]-[11]. The system frequency will be stabilized or increased if the load drop is sufficient but if the first load shed is not sufficient, the frequency keeps on falling with a slower rate. When the system frequency reaches a second threshold another block of load is shed. This process will continue until the overload condition is relieved or all the frequency sensitive (FS) relays have operated [11]. The threshold frequencies and the amounts of load to be shed are decided offline based on simulation and experience [5]-[6]. In adaptive load shedding scheme the amount of load blocks to be shed is being decided by the frequency droop (FD) relay and frequency sensitive (FS) depending on the value of ROCOF whereas for traditional scheme load shedding amount is decided by only frequency sensitive (FS) relay [11].

Digital fault data recorder (DFDR) is installed on grid of a power system to record frequency, current and voltage which has been reported in [5]-[6], where load shedding techniques based on magnitude and ROCOF during abnormal condition are discussed. According to [12]-[14], traditionally islanding detection methods are divided into two major subgroups such as: passive and active methods. There are some other islanding detection methods such as hybrid detection method which combines both active and passive method, utility detection method based on communication between grid and DGs. A typical comparison between islanding detection methods is reported in [13]. According to [14]-[15], though islanding is the final resort at the time of extreme abnormalities but it is a very weak system. The equipments and devices may fail due to unsuitable power quality of island. Well planned protection and operation schemes are required as islanding operations are more complicated than normal operations. In addition, generators may be damaged due to inappropriate operation and safety of the line crew is one of the major concerns during islanding operation. Furthermore, squirrel case induction generator cannot operate during islanding operation but only synchronous generator.

There are a huge number of literatures regarding load shedding scheme and intentional or forced islanding to prevent blackout. But only few [5]-[6], [14]-[18] studied the impact of different abnormal phenomena such as sudden load addition or load rejection, generation outage, combination of both load addition and generation outage, large motor starting, different types of faults inside island. As the islanded systems are weaker than integrated system; even a small disturbance causes significant effects on islanding operation which leads to fluctuation in voltage, current, frequency and power factor making power quality poor. So to improve service reliability and stability of islands; detail studies are required.

In this paper section I introduce an introduction along with literature review whereas section II presents a general theoretical background of power system stability. Section III describes the system under study and section IV shows the simulation results of a generation Rich Island which is mainly the Dhaka region of Bangladesh power system (BPS) and the concluding remark is presented in section V.

II. POWER SYSTEM STABILITY

Power system stability is the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact [11]. Therefore, the system is said to remain stable when the forces tending to hold the machines in synchronism with one another are enough to overcome the disturbances. The system stability that is of most concern is the characteristic and the behavior of the power system after a disturbance.

Power system stability may be affected by system inertia constant, dynamics of rotor angles and power-angle relationships, load and generation mismatch, location, duration and type of the faults etc. Preventive actions to stabilize a faulted power system can be ramified mainly into offline and online preventive actions. Offline preventive measures include organizing the system configurations and maintenances, reduction of transmission system reactance, activation of new generation facilities for reactive power support and voltage control, connecting dynamic breaking resistors at the generator and substation terminals etc. On the other hand, Online preventive measures include changing the system topology by tripping of critical generator, using of high-speed protective schemes, effective use of online transformer tap-changers and phase shifters, automatic load shedding (ALS) of interruptible consumers, assuring reactive-power generation or absorption to maintain generation/load balance, implementation of high-speed excitation systems etc. [19].

The ramification of power system stability is essential for the better understanding of EPS stability analysis. The classification [20] of stability is based on the nature of resulting system instability (voltage instability, frequency instability, and rotor angle instability), the size of the disturbance (small disturbance, large disturbance) and time frame of instability (short term, long term). Fig. 1. shows the general and widely accepted classification of power system stability [21].

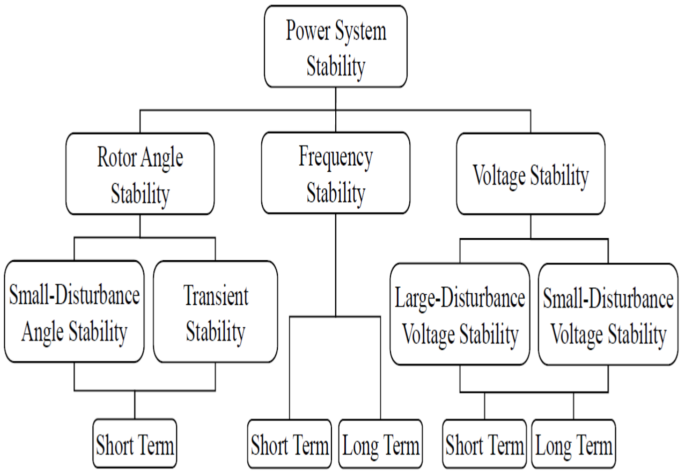

Fig. 1. Classification of stability based on IEEE/CIGRE joint task force on stability.

III. MODEL DESCRIPTION AND SIMULATION TECHNIQUE

A. System Description:

Bangladesh power system (BPS) is a small system with a peak demand of around 7000 MW whereas the install capacity is about 6700 MW. The transmission system of BPS has been formed with an integral grid of two voltage levels of 132kV and 230 kV. The BPS grid network is inherently radial in nature and divided into six regions which is shown in fig. 2. and status of different regions are shown in table I.

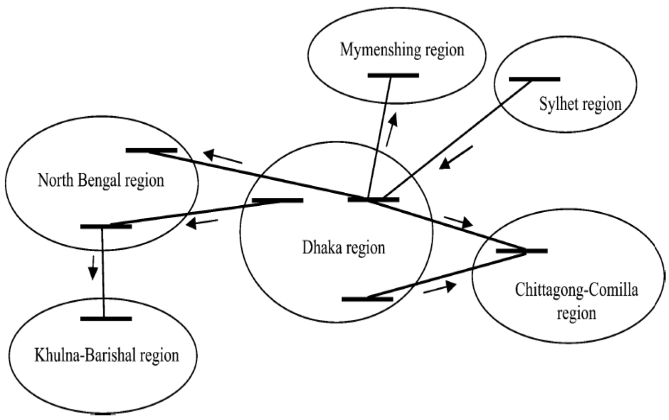

Fig. 2. Radial nature of Bangladesh Power System (BPS) [6]

Table I: Generations and Demands of Different Regions (Islands) of BPS

Region (Island)	Available Generation (MW)	Demand (MW)	Losses (MW)	Status
Dhaka	3016	2119	28	Generation rich
Chittagong-Comilla	577	833	13	Load rich
Sylhet	456	283	6	Generation rich
Mymenshing	203	350	11	Load rich
North Bengal	386	817	36	Load rich
Khulna-Barisal	607	729	20	Load rich
Total	**5245**	**5131**	**114**	---

B. *Simulation Technique:*

The procedures that have been followed are:

Step 1: The load and the generation have been matched for Dhaka Island.

Step 2: Maximum amount of load addition and generation outage have been measured by simulation without activating any types of relays.

Step 3: Percentage of load shedding to stabilize the island for different transient phenomena such as sudden load addition, generation loss or for combined effect of both have been measured through simulation and compared through a developed auto load shedding scheme. Steps that have been followed to develop auto load shedding scheme for the island are given below:

Step 1: System frequency and ROCOF have been monitored continually.

Step 2: If the system frequency falls below a certain threshold and the ROCOF has become less than a pre-specified value, then traditional load shedding scheme has been activated but for a greater ROCOF the adaptive load shedding scheme has been activated.

Step 3: Once ROCOF based scheme is activated it starts counting time. After a preset time delay if the frequency is still below than the threshold value; the system activates traditional load shedding scheme to stabilize system operating frequency to a certain value.

C. Relay settings:

Both frequency droop (FD) and frequency sensitive (FS) relays are used for adaptive load shedding scheme whereas for only frequency sensitive (FS) relay is used for traditional load shedding scheme and there settings are given in table II & III.

Table II: FS Relay Settings

FS Relay Settings		
Relay Type	**Frequency Threshold**	**Load Shed Amount (%)**
FS1	49.00	10
	48.80	10
	48.60	15
FS2	49.10	10
	49.00	10
	48.90	10

Table III: FD Relay Settings

FD Relay Settings		
Relay Type	**ROCOF (Hz/sec)**	**Load Shed Amount (%)**
FD1	-0.20	10
	-0.30	15
	-0.40	20
FD2	-0.01	10
	-0.02	10
	-0.04	15

The operating times of relays are 0.01 seconds and both FS and FD relays are connected to all buses of the network.

IV. SIMULATION RESULTS AND DISCUSSIONS

As the generation capacity of the island Dhaka is 3016 MW and the load demand is 2119 MW, thus the island is called generation rich. Case A, case B and case C of fig. 3. show the frequency responses for 32.50 % (689 MW), 36.23 % (768 MW) and 54.27 % (1257 MW) load addition to the system respectively. It is observed from the figure when the total amount of loads becomes larger (case C) than the generation capacity because of load addition to the island; it will make the system unstable.

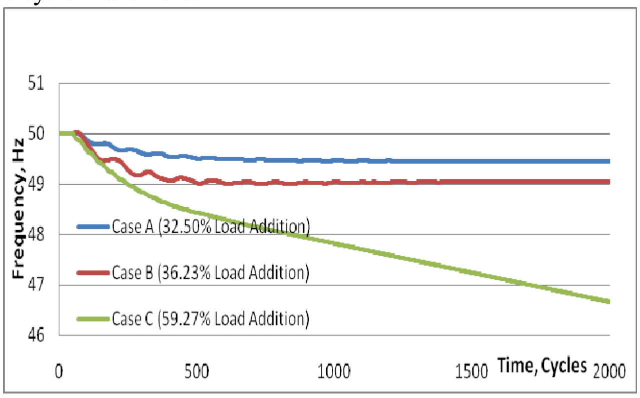

Fig. 3. Frequency response for load addition in a Dhaka island

Fig. 4. shows the frequency response characteristics (FRC) of a generation rich island (Dhaka) for different amount of generation outages. Case A and Case B refer FRC for 39.03% (1177MW) and 44.37% (1338 MW) generation outages respectively. It is inferred from case B that if the generation capacity become lower than the load demand because of forced shut down of generators, it makes the system unstable. After matching the generation and load demand for island Dhaka to 2100 MW; it has been simulated. Fig. 5. shows the fall of frequency in Dhaka region (island) in case of load addition when no relay is being activated to shed load; case A refers system frequency remains within an accepted range up to a load addition of 13.55% (284 MW) whereas case B refers in case of 15.89 % (334 MW) load addition, here the system frequency goes below the accepted range making the system unstable.

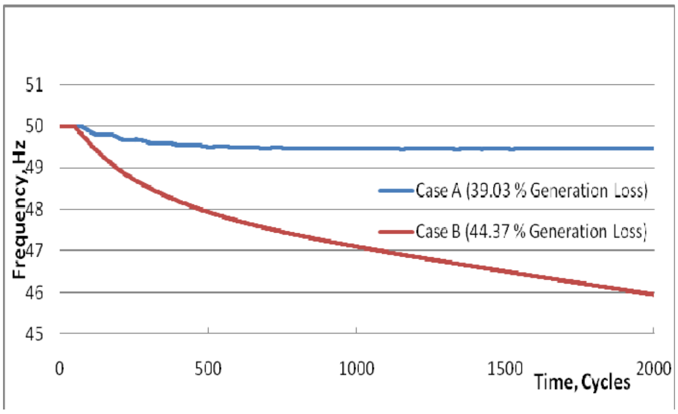

Fig. 4. Frequency response for loss of generation in a generation rich island

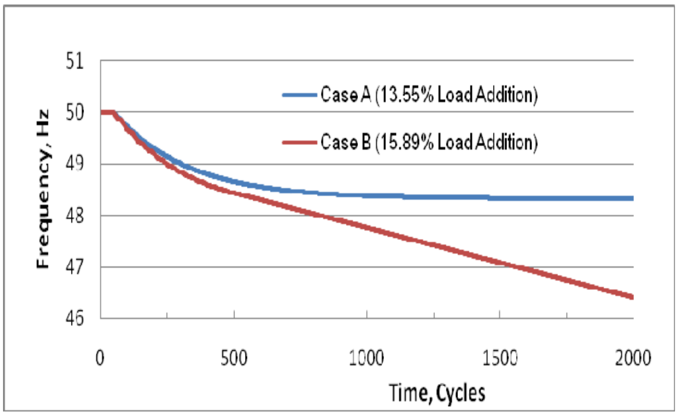

Fig. 5. Frequency response of Dhaka Island for load addition

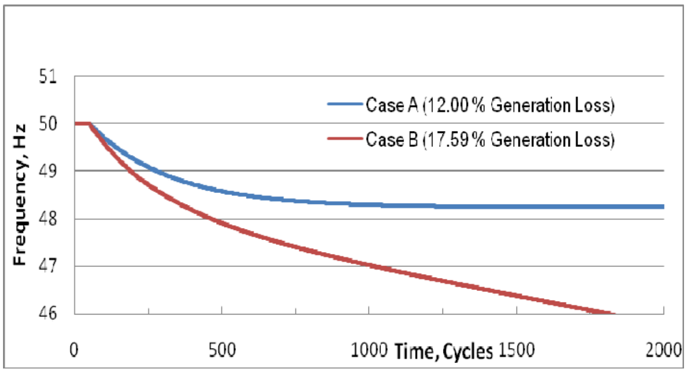

Fig. 6. Frequency response of Dhaka Island for generation loss

The fall of frequency in Dhaka region (island) in case of generation loss when no relay is being activated to shed load in fig. 6.; case A refers system frequency remains within an accepted range up to a generation loss of 12.00% (252 MW) whereas case B refers the situation when 17.59% (369 MW) generation loss occurred to the system which makes the system unstable as the system frequency goes below the accepted range. Auto load shedding scheme developed by using relays may stabilize the system for larger amount of load addition or generation loss. Fig. 7. shows the frequency response of Dhaka region (island) in case of load addition where an auto load shedding scheme has been applied using only FS relays to stabilize the system frequency within an accepted range; case A refers system frequency remains within an accepted range up to a load addition of 60.75% (1276 MW) whereas case B refers the case of 70.11% (1472 MW) load addition. It is clear from the figure that for case B system load addition makes the system unstable though load shedding scheme has been applied using FS relays.

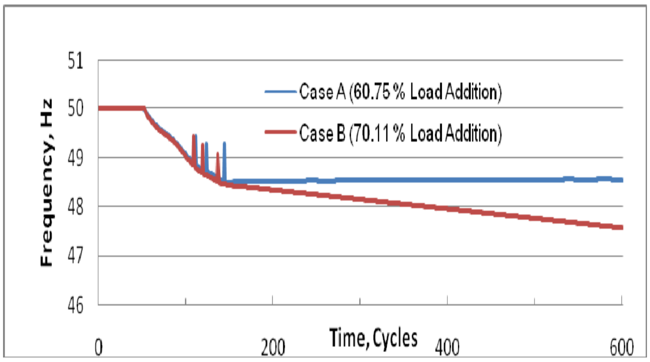

Fig. 7. Frequency response of Dhaka Island with only FS relay based load shedding.

An auto load shedding scheme has been applied using both FS and FD relays to Dhaka Island and FRC is shown in fig.8. Case A and case B refer system frequencies remain within accepted range for 70.11% (1472 MW) and 100.07 % (2101 MW) load addition. Case C of the figure clearly depicts addition of 105.14% (2207 MW) load to the system makes the system unstable as auto load scheme fail to maintain system frequency within accepted range.

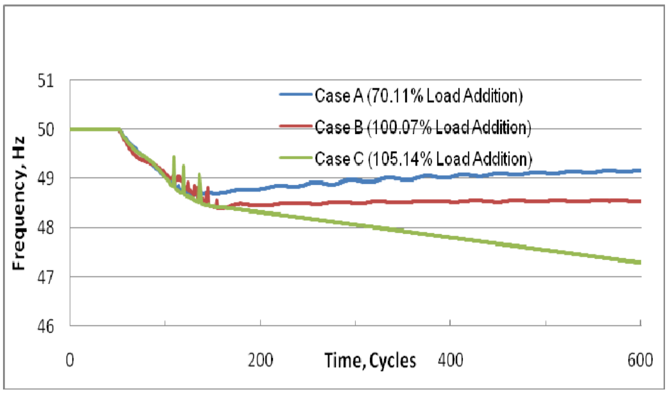

Fig.8. Frequency response of Dhaka Island with both FS & FD relay based load shedding for load addition.

The frequency response of Dhaka region (island) in case of generation loss where an auto load shedding scheme has been applied using FS relays to stabilize the system frequency within an accepted range is shown in fig. 9. Case A refers system frequency remains within acceptable range up to a generation loss of 36.24 % (761 MW) whereas case B refers in case of 43.48% (913 MW) generation loss the system frequency goes below the accepted range making the system unstable.

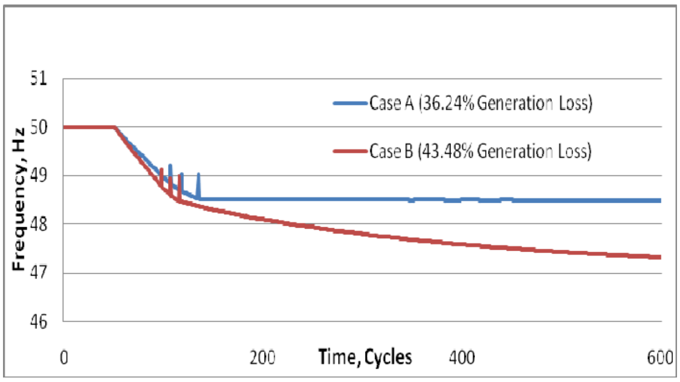

Fig. 9. Frequency response of Dhaka Island with only FS relay based load shedding for generation outage.

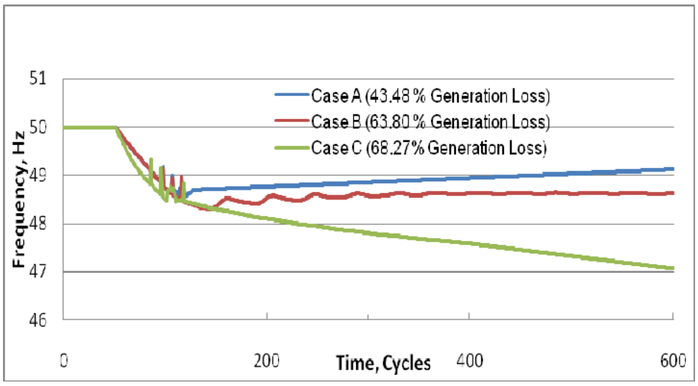

Fig. 10. Frequency response of Dhaka Island with both FS & FD relay based load shedding for generation outage.

Fig. 10. shows the frequency response of Dhaka region (island) in case of generation loss where an auto load shedding scheme has been applied using both FS and FD relays to stabilize the system. It is observed from Case A and case B system frequencies are within accepted range for generation outages of 43.48% (913 MW) and 63.80% (1340 MW) respectively. When the generation loss became 68.27% (1413 MW), the system frequency goes below the accepted range making the system unstable which is shown in case C.

Fig. 11. shows the performance of the load shedding scheme during combined effect of both generation loss and load addition using only FS relay under some of the scenarios namely case A, case B, and case C. Table IV summarized the three different cases, where the load shedding scheme could prevent the continuous fall of system frequency, stabilize, and prevent the system from blackout. Case A and B of fig. 11. show load shedding scheme maintain system frequency within accepted range where for case C the system frequency falls below the accepted range and makes the system unstable.

Table IV: Percentage of load addition and generation loss for fig. 11

Case	Case A	Case B	Case C
Load Addition	36.36%	32.72%	53.75%
Generation Loss	16.90%	19.40%	26.60%

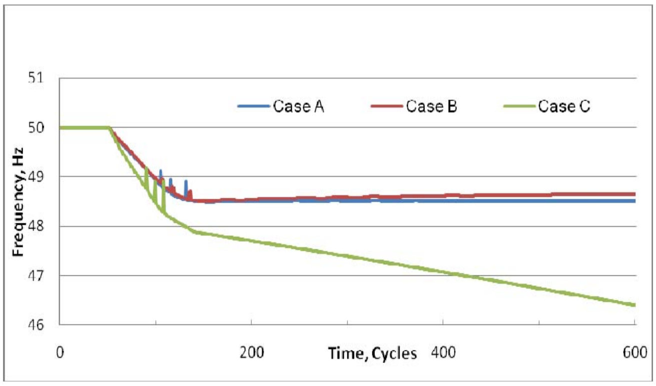

Fig. 11. Performance of load shedding scheme using only FS relay on Dhaka Island

Fig. 12. shows the performance of the load shedding scheme using both FS and FD relays under some conditions namely case A, case B, case C and case D. The cases are summarized in table V. It is observed from cases A, B and C the auto load shedding scheme maintain system frequency within accepted range where for case D the frequency falls below the accepted range making the system unstable.

Table V: Percentage of load addition and generation loss for fig. 12

Case	Case A	Case B	Case C	Case D
Load Addition	53.75%	71.98%	60.52%	70.95%
Generation Loss	26.60%	26.60%	35.60%	35.60%

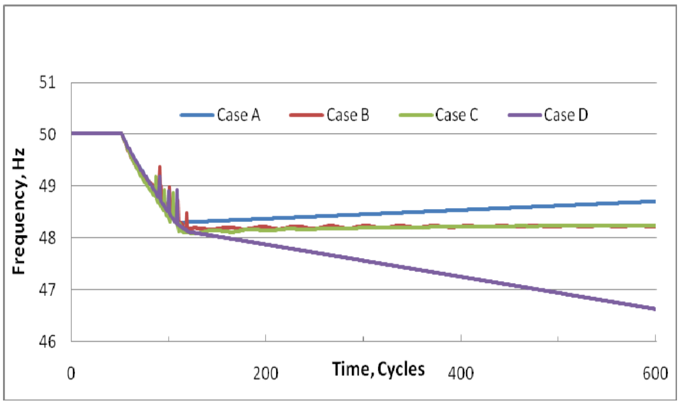

Fig. 12. Performance load shedding scheme using both FS & FD relays on Dhaka Island.

V. CONCLUSION AND FUTURE DIRECTIONS

To provide continuous supply to critical and important loads and to improve system reliability in case of extreme abnormalities, system disintegration has been performed. These types of operations also reduce system losses and hence increase revenue to a system. This paper deals with different phenomena inside a generation rich island and shows how system frequency is affected because of sudden load addition, generation outage and combined effect of both. The traditional and adaptive load shedding schemes have been developed. The developed auto load shedding schemes have been applied to a generation rich Island (Dhaka region of BPS) to validated the scheme and from the simulation results it is clear that the technique is capable of handling abnormal conditions to the island. Along with load rich island different sizes of islands can be simulated and the results can be compared with a view to develop a principle of sizes/types of islands on the stability of faulted network.

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