Impacts of Sizes of Islands on the Stability of a Faulted Power System

by

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Dedication

To my beloved parents

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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 is the part of a power system consisting of generally one or more power sources and load, that is islanding is a situation in which a portion of the utility, comprising of both loads and generation sources, is isolated from the rest of the system for some period of time but remained energized. In case of emergency, islanding operation not only helps stabilizing a faulted system but also supports power supplies to critical and important loads.

This thesis investigates the islanding technique, used to stabilize a power system under a severe condition and prevent blackout, with a view to develop a principle of the formation of islands. To do so the stability of a power system for different sizes (in terms of MW) and natures of islands such as load rich or generation rich are studied. The simulation results are compared to find a logical conclusion. In this study Bangladesh Power System (BPS) is considered. Islands of different sizes and natures are formed by disintegrating BPS. CYME PSAF (Power System Analysis Framework) has been used for the simulation purpose. The investigation clearly shows that an island with higher inertia constant (H), performs better from the stability point of view.

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List of Abbreviations

BPS	Bangladesh Power System
CIGRE	Conseil International Des Grands Réseaux Électriques (French)
DFDR	Digital Fault Data Recorder
DG	Distribution Generator
EWI	East West Interconnector
FACTS	Flexible AC Transmission System
FD	Frequency Droop
FS	Frequency Sensitive
GR	Generation rescheduling
GWh	Giga Watt Hour
HVDC	High Voltage Direct Current
IEEE	Institute of Electrical and Electronic Engineers
kV	Kilo Volt
LDC	Load Dispatch Center
LG/LL	Line to Ground/ Line to Line
LLG/LLL	Double Line to ground/ Three Phase Symmetric Fault
LS/MW	Load shedding/ Mega Watt
MVA/MVAR	Mega Volt Ampere/ Mega Volt Ampere Reactive
NERC	North American Electric Reliability Council
PSAF	Power System Analysis Framework
ROCOF	Rate of Change of Frequency
SFR	System Frequency Response
SLD	Single Line Diagram
TSR	Transmission System Reconfiguration
OBBD	Ordered Binary Decision Diagram

List of Symbols

H	Inertia constant
J	Moment of inertia
Ω	Nominal speed of rotation in rad/s
G_{mach}	MVA rating of the machine.
ΔP	Megawatt of load addition or generation lost.
ω_{sm}	Synchronous speed in rad (mech)/s
T_a	Accelerating Torque
f_0	Initial Frequency (System Frequency)

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Chapter 01

Introduction

1.1 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. Nikola Tesla has invented induction motor in 1888, which signaled the growing importance of electrical energy in the industrial world as well as its use for non-industrial world. A major portion of the energy needs of a modern society is the electrical energy.

Due to the increasing number of sophisticated consumers, requiring electric supply of high reliability, the need for power system stability study is inevitable. Power system stability has been recognized as a vital and important issue for a reliable and secure system operation as far back as the 1920s. 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.

The North American Electric Reliability Council (NERC) Planning Standards define two components of reliability, a) adequacy of supply and b) transmission security: Adequacy is the ability of electric systems to supply the aggregate electrical demand and energy requirements of customers at all times, taking into account scheduled and reasonably-expected unscheduled outage of system elements. Security is the ability of electric systems to withstand sudden disturbances such as electrical short circuits or unanticipated loss of system elements.

The electrical quantities such as voltage, frequency and current of a power system fluctuate because of disturbances and in some cases a condition may arise which leads to fall of frequency. System blackout may occur in case of extreme abnormalities; but planned and proper islanding may protect the system and prevent from blackout. Though traditionally, interconnection principle is against the concept of islanding operation but in case of extreme emergency islanding can support power supplies to critical and important loads to improve the service reliability.

1.2 Literature Review

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.

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 [7]. Nowadays, power system stability and reliability is an inevitable part of power system studies and operation, due to significant increase of the number of industrial electrical consumers, requiring high reliability of electric supply.

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 [8] 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 [9].

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 [10]-[12]. 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 [12]. The threshold frequencies and the amounts of load to be shed are decided offline based on simulation and experience [5]-[6],[10].

But the traditional load shedding scheme is not capable to distinguish between the normal oscillations and the large disturbances to the power system. As this scheme has lack of information regarding the magnitude of the disturbances the settings are considered as mostly conservative. Although this approach is effective in preventing inadvertent load shedding in response to small disturbances with relatively longer time delay and lower frequency threshold but it is prone to shedding lesser loads during large disturbances [5]-[6].

The frequency decline rate is used as a measure of the generation shortage in semi-adaptive load shedding scheme [13]. This scheme measures the rate of change of frequency (ROCOF) and according to the values of ROCOF different amounts of loads are being shed. The scheme checks also the speed at which the threshold is exceeded; for a higher rate a larger block of load will be shed whereas for a lower rate a smaller block of load will be shed. The amount of load blocks to be shed is being decided by the frequency droop (FD) relay depending on the value of ROCOF whereas for traditional scheme load shedding amount is decided by frequency sensitive (FS) relay. The threshold values of ROCOF and the sizes of load blocks to be shed for different thresholds are decided offline based on simulation and experience. This scheme adapts to the system disturbances and is able to shed a block of load according to the value of ROCOF.

In [14], adaptive load shedding scheme has been presented which uses the frequency derivative and is based on system frequency response (SFR). A reduced order SFR model is used to obtain a relation between the initial value of ROCOF and the size of the disturbance that caused the frequency decline [15]. In this scheme the amount of load to be shed and its location is determined in real time.

Different load shedding schemes based on frequency thresholds, frequency and voltage changes, ROCOF, magnitude of the disturbances, load frequency regulation factor and so on are described in [16]-[19]. But all of them fall under any of the three categories described above.

A load shedding scheme utilizing frequency and voltage changes in the most affected localities while regaining the load generation balance for each incident is described in [18]. This scheme sheds load in proximity to lost generator using change of voltage, frequency and frequency decline rate.

Load shedding near the lost generator is more effective which has been reported in [18] and the objectives and principles of under frequency load shedding schemes are reviewed in [20].

A defence system based on load shedding, which can assess power system vulnerability and perform self healing, corrective and preventive control action is proposed in [21]. It is designed with multi agent system technologies to provide greater flexibility and intelligence.

To protect electric power system from dynamic instability and frequency collapse a typical procedure is proposed in [22], which consists of two main stages. In the first stage frequency and ROCOF are estimated by non recursive Newton type algorithm and in the second stage the magnitude of the disturbances are determined hence the number of steps, frequencies, time delays and the amount of load to be shed from the network in every step is determined.

A technique of choosing load shedding point based on the online measurement of loads and the derivative of active power with respect to frequency i.e. load frequency regulation factor is reported in [23]. Here the loads with smaller frequency regulation factors are shed earlier and than those with larger frequency regulation factors.

An intelligent, optimal and fast load shedding technique has been presented in [24] which generally known as ILS (Intelligent Load Shedding). To continually update dynamic load shed tables ILS combines online data, equipment ratings, user define control logics and a knowledge base obtained from power system simulation studies. Two industrial electrical networks have been simulated to demonstrate the advantages of ILS over conventional load shedding schemes. Different approaches of under frequency load shedding schemes are reported in [25]-[27].

A comprehensive preferential load shedding scheme is developed in [28] by indexing the load buses based on electrical proximity and generator, generator inertia constant and size of the load for restoring system frequency more quickly while removing fewer loads. This technique reduces active power absorbed by the loads and makes the system frequency restoration faster.

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. In case of extreme abnormality the integrated system is splitted into several islands and techniques to stabilize the islands are reported. According to the literature, the islands may be load rich or generation rich. In case of load rich islands load shedding scheme is required and for generation rich islands generation must be reduced to balance the system during transition to islanding operation, system will have a small oscillation if the difference between total generation and total load is small. Splitting a grid system into a number of independent islands can be considered either as a last resort or as a primary measure depending upon the structure of the system. To prevent further blackout the new load shedding schemes are applied to islands also.

In [18], it is reported that how a blackout can be prevented in real time through controlled segregation of a system into number of viable islands together with generation and/or load shedding. The islanding is accomplished through monitoring the active power flows at both ends of a number of pre specified lines. If the megawatt flow changes between two successive samplings an intersection line is tripped. Depending upon the location and severity of the fault the system will be splitted into two or more islands or none.

Literature [11], presented that abnormal condition in a power system generally leads to fall of system frequency and emergency load shedding schemes are applied to prevent the degradation of frequency by balancing the load and generation of the system. But when the rate of change of frequency become higher and the system could not be stabilized by load shedding scheme then an integrated power system would be disintegrated into different zones for the higher service reliability or to prevent system blackout. Additionally, sometimes for maintenance purpose some portion of an integrated system has to be separated to provide continuous supply of energy to important loads, hence islanding can be classified as inadvertent or intentional. The intentional islanding is preferably done with a minimal load flow to/or from the main grid but inadvertent islanding occurs during a heavy load flow to/or from the main grid.

In [17], a self healing strategy is proposed to deal with catastrophic events when power system vulnerability analysis indicates that the system is approaching an extreme emergency state. Here the system is adaptively divided into smaller islands with consideration for quick restoration. After islanding ROCOF based load shedding scheme is applied which raises the stability performance of the system by shedding less load compared to conventional load shedding scheme. Since the tripping action does not require much calculations and the islanding information can be obtained offline, the speed of the real time implementation mostly depends on the speed of the communication devices and switching actions. In order to facilitate restoration, islands are formed by minimizing the generation load imbalance.

According to [29], to prevent blackout in an extreme abnormality the islanding has been initiated to an integrated system to improve service reliability and to increase revenue. Partial disintegration of a power system can support continuous and uninterrupted power supply to critical and important loads as well as reduce the amount of losses.

Power system controlled islanding is the last defence line against wide–area blackout of interconnected power networks. Controlled system islanding is to determine the proper splitting points for separating the entire power network into smaller islands when preservation of integrity of power network is inevitable [18], [30]-[32]. When a system is affected with severe instability problem, and emergency control fails to bring the faulted system back to the normal state, an islanding strategy is executed and splits the interconnected power network into several islands by disconnecting selected transmission lines.

In [18], a slow coherency based islanding strategy is developed for large disturbances. The analytical basis for an application of slow coherency theory to the design of an islanding scheme is provided which is employed as an important part of a corrective control strategy to deal with large disturbances. The results indicate that the slow coherency based grouping is almost insensitive to locations and severity of initial faults. However because of the loosely coherent generators and physical constraints the islands formed changed slightly based on location and severity of disturbances and loading conditions. A detailed procedure of formation of islands after grouping the generators using slow coherency is presented which includes the development of grouping procedure and identification of weakest link/links in the network.

According to [33]-[39], 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 [39].

In [29], it is extensively reported that islanding is an approach of preventing blackout in an extreme abnormality. But the question is what the buses are where the network should be disconnected to form an island. The formation of islands is not unique. In

[40]-[43], the graph partitioning methods of islanding formations are widely discussed. There are some other major approaches of formation of island such as minimal cutset enumeration [44], and generator grouping [45]–[47]. In Reference [48], an interesting method based on the occurrence of singularity in Newton power flow is illustrated. Another interesting method for system splitting by using the OBDD technique is reported in [32].

In the case of splitting a system into two islands, each load bus belongs either to one island or the other. Finding the weak link/links between different zones of power system is the target of these approaches. For a radial nature power system it's easier to find the bus/buses where the system can be disintegrated by carefully inspecting the mismatches between loads and generations of different zones which is discussed in [5]-[6]. The basis for islanding is never unique but rather depends upon the utility in particular.

According to [49]-[50], 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.

The frequency behaviour of a generator depends on different parameters such as generator inertia constant, generator damping constant, governor gain and electrical distance of the disturbance from the generator [51], when a disturbance occurred in the network. It is observed that generator damping and governor gain has no significant effect on the initial frequency behaviour of a generator after a disturbance.

Minimum frequency deviations belong to the generators with larger inertia constant (H), greater electrical distance from the location of disturbance and less electrical distance from the slack generator. After calculating amount of overloads and disturbing conditions the amount of loads to be shed is determined.

It is described in [52] that immediately after the load change impact of power system network, the machines share the impacts immediately according to their electrical proximity to the point of impact and after a short transient period of time machines share the impact according to their inertia constant (H).

In [53], it is described that disturbances in an interconnected power system lead to frequency deviations in grid. The frequency deviation is primarily characterized by the amount of inertia of the system. The inertia constant (H) describes the characteristics of the system; the bigger value of this constant refers the higher stability of the system. It is apparent that the system frequency stability is very much dependent on the overall H constant of the system.

For a multi machine system the H constant increases with the increase of number of machines connected to the system. That means a system with higher number of active generators will have higher inertia constant than a system with lower number of active generators hence the larger system shows more stable operation than a smaller system which has been presented in [54].

Although for last few decades there were remarkable efforts on controlled islanding of power system, but yet there are some unsolved problems in the area of the system separation [55]. Transient stability, frequency stability within the islands and development of real-time algorithm for proper splitting which includes both static and dynamic constraints of the islands, are complicated tasks and need for detail studies.

A new algorithm based on combination of both static and dynamic characteristics of power systems to determine proper islanding strategy has been presented in [56].

There are a huge number of literatures regarding load shedding scheme and intentional or forced islanding to prevent blackout. But only few [5]-[6], [49]-[50], [57]-[59] 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.

1.3 Thesis Organization

The thesis paper has been organized in six chapters where the chapter 1 introduces an introduction along with literature review and thesis organization.

The other part of the thesis is organized as follows: chapter 2 introduces a general theoretical background of power system stability and contribution of inertia constant for system stability. The chapter includes the necessity of power system stability, factors affecting power system stability, technique of stabilizing a faulted power system and classification of power system stability. Importance of inertia constant, relationship of ROCOF and inertia constant are also presented in this chapter.
Chapter 3 deals with the islanding of a power system which includes the necessity of islanding, types of islanding, islanding detection methods and different techniques of islanding.

The simulation techniques and proposed simulated systems are presented in chapter 4. Simulation technique along with simulation steps and relay settings are discussed in this chapter.

Chapter 5 includes the simulation results of different sizes of islands (Dhaka and Khulna-Barisal region) along with the comparison of the results with a view to develop the principle of formation of islands during disintegration of a faulted power system.

The last chapter, chapter 6, presents conclusions from the thesis. The chapter presents brief concluding remarks along with suggestions for future works.

Finally references and appendices related to the thesis are appended at the end of the report.

Chapter 02

Power System Stability and Inertia Constant

2.1 Introduction

An unbalance situation is occurred between the generation and load of a power system when the system operating under a steady load condition is perturbed, which results in the establishment of a new steady-state operating condition, with the subsequent adjustment of different parameters of the power system such as voltages, currents, frequency, power factors etc. The perturbation could be a major disturbance such as the loss of a generator, addition or rejection of load, a fault or the loss of a line, or a combination of such events. It could also be a small load or random load changes occurring under normal operating conditions.

An interconnected power system basically consists of several essential components such as generating units, the transmission lines, the loads, the transformer, static VAR compensators and lastly the HVDC lines, therefore an EPS is being considered one of the most complex systems to be planned and safely operated. This complexity arises as a consequence of the large amount of devices contemporaneously in operation, each one with its own internal dynamics, that however interact with each other, giving rise to a complex collective behavior. The wide geographic extension of electric power systems that can span entire countries and even continents, adds even greater complexity to issues connected to their analysis and control.

Disturbances may occur during the operation of the generators due to continuous oscillation. External factors such as lightning and others also cause disturbances to a power system. Furthermore, power system undergoes a large number of disturbances like modifications in loads, generations continually during its operation.

To secure the stability of a power system, the adjustment to the new operating condition is required and the behavior of the system during this period of time is known as dynamic system performance. Maintenance of synchronism of synchronous machine is the main criterion for stability. Safe operation of electric power system is largely related to its stability which depends on the ability in making all generators supplying the network rotate synchronously despite faults and other contingencies.

Power system stability, necessity of stability, factors affecting the system stability, classification of stability, concept of inertia constant in power system, its importance and mathematical modeling of inertia constant will be discussed in this chapter.

2.2 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 [13].

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.

2.2.1 Necessity of Power System Stability

The variables of power system change continually and the power industries are structured to cater to more users at lower prices with better efficiency. The demand of electricity is increasing regularly with the increase of users and power systems are becoming more complex as they are inter- connected. Since stability phenomena limit the transfer capability of the system; there is a need to ensure stability and reliability of the power system due to economic reasons.

The performance of a power system is affected when any type of disturbances occur in the system which result insufficient supply of power to the users or loss of power. In order to compensate for the fault and to resume normal operation, corrective measures must be taken to bring the system back to its stable operating conditions.

2.2.2 Factors Affecting the Power System Stability

The power system is a highly nonlinear system that operates in a constantly changing environment; loads, **generators,** outputs, topology, and key operating parameters change continually. Stability of a nonlinear system depends on the type and magnitude of inputs, and the initial states. Behaviors and characteristics of system equipments, system control and protection schemes etc are the factors those affect the stability of an Electric Power System.

The following discussions summarized the most important factors:

- Synchronous machine parameters such as the inertia constant H (stored kinetic energy at rated speed per rated power), and the generator terminal voltage are affect the system stability. The increase of generators inertia constant tends to reduce the swings of rotor angle and hence improve system stability.
- The stability is influenced by the dynamics of generator rotor angles and power-angle relationships. Instability may also be encountered without the loss of synchronism. For example, a system consisting of a generator feeding an induction motor can become unstable due to collapse of load voltage. In this instance, it is the stability and control of voltage that is the issue, rather than the maintenance of synchronism. This type of instability can also occur in the case of loads covering an extensive area in a large system.

- System stability is affected by a significant load/generation mismatch, generator and prime mover controls become important, as well as system controls and special protections. If not properly coordinated, it is possible for the system frequency to become unstable, and generating units and/or loads may ultimately be tripped possibly leading to a system blackout. This is another case where units may remain in synchronism (until tripped by such protections as under-frequency), but the system becomes unstable.
- The duration, location and type of the fault determine the amount of kinetic energy will be gained. Longer fault duration allows generator rotors to gain more kinetic energy during the fault. At certain limit, the gained energy may not be dissipated after the fault clearance. This gained energy may lead to instability.
- Pre-and-post-disturbance system state such as the generators loading before the fault and the generator outputs during the fault. The higher the loading before the fault is the more likely to be less stable during faults.
- Transmission reliability margin greatly affect the system stability where a transmission outage may take place due to overloading during system abnormal conditions, which may lead to uncontrolled loss of a sequence of additional network elements.
- Excitation system and governor characteristics of synchronous machines have important role in damping of power oscillations. The automatic voltage regulator (AVR) senses the terminal voltage and helps to control it by acting within the excitation system. Fast valving for rapidly opening and closing steam valves of the turbine used to control the generators accelerating power during faults.
- System relaying and protection have a great importance in system stability. The power system has a finite capacity to absorb such energy and as majority of fault are transient in nature, rapid switching and isolation of unhealthy lines followed by rapid reclosing improves the stability margins. Special protection

schemes can be used to split the grid at predetermined points in the network to quickly avoid cascading actions.

2.2.3 Technique of Stabilizing a Faulted Power System

In power system design and preparation stage, a wide number of disturbances have to be assessed by system operators. If the system is found to be unstable (or marginally stable) following any contingency, variety of actions can be taken to improve the system stability. These preventive actions can be ramified mainly into offline and online preventive actions.

Offline preventive measures: Improvement of system stability can be achieved by many offline actions including:

- Organizing the system configurations and maintenances in such that being suitable for the particular operating conditions without overloading during abnormal conditions.
- Reduction of transmission system reactance which can be achieved by adding additional parallel transmission circuits, providing series compensation on existing circuits and by using transformers with lower leakage reactance.
- Activating new generation facilities for reactive power support and voltage control service such as power system stabilizers, FACTs, distributed generation technologies, and rapid thermal units with fast valving capability and fast acting automatic excitation systems.
- Connecting dynamic breaking resistors at the generator and substation terminals in order to break the acceleration of the rotor of generators during faults. Shunt resistors can be switched in to create an artificial load following a fault, in order to improve the damping.

- Installation of efficient protective devices and coordination between the interconnected system operators for faster fault clearing and initiating proper corrective actions during abnormal conditions.

Online preventive measures: There a lot of online preventive measures to stabilize system stability, such as:

- Changing the system topology by tripping of critical generator to ensure that the other generators maintain the synchronism. In addition, generation rescheduling/re-dispatching can be used to reallocate power generation in order to avoid system overloads and relieve constraints.
- Using of high-speed protective schemes such as transmission line protection with single-pole tripping and adaptive reclosing capabilities to minimize system disturbances. High-speed automatic reclosing system is effective methodology to restore power continuity.
- Effective use of online transformer tap-changers and phase shifting transformers to control the power flow across transmission system.
- Automatic load shedding (ALS) of interruptible consumers is an effective corrective counter-measure to maintain the frequency at nominal value during abnormal conditions. This ALS can be achieved by installing under frequency relays at fixed points with fixed settings.
- Assuring reactive-power generation or absorption to maintain generation/load balance in networks during disturbances.
- Implementation of high-speed excitation systems to boost rapidly the field voltage in response to disturbances.

The operation of electrical transmission systems has to be more flexible under competition. An optimal use of the operating 'network' can be achieved by running the system closer to the stability limit. If economical requirements can be realized technically, it is essential to check the distance to the stability limit.

2.2.4 Classification of Power System Stability

The ramification of power system stability is essential for the better understanding of EPS stability analysis. The classification 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)[52]. In other terms, stability broadly may be classified as steady state stability and dynamic stability. Steady state stability is the ability of the system to transit from one operating point to another under the condition of small load changes. Power system dynamic stability appears in the literature as a class of rotor angle stability to describe whether the system can maintain the stable operation after various disturbances or not. Fig. 2.1 shows the general and widely accepted classification of power system stability [63].

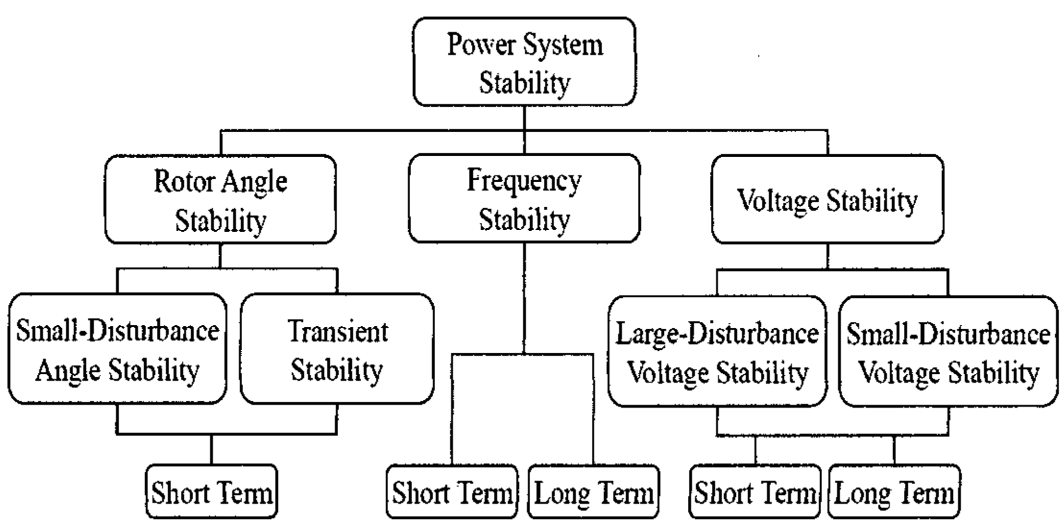

Fig. 2.1 Classification of stability based on IEEE/CIGRE joint task force on stability.

2.3 Inertia Constant of a Power System

The moment of inertia is defined as the product of rotating mass and the square of the distance from the center of rotation. A rotating mass has characteristics of an energy storage device. During acceleration, energy is stored, and during deceleration, it is released. In the case of a negative frequency deviation, during acceleration, the system's moment of inertia works against frequency control efforts because it is storing rotational energy; during deceleration the moment of inertia helps to control frequency by releasing previously stored rotational energy. The equivalent moment of inertia of a system is the combination of moment of inertias of the connected power generating units, including both the prime mover and the generator.

Due to the rotating mass of the large spinning machines such as rotor, driving turbine shaft etc, energy store in generators. When a disturbance occurs e.g. the unanticipated loss of a generator, addition of load or combined effect of load addition and generation loss, the stored energy is released to the system to make the system stable.

2.3.1 Inertia Constant and ROCOF

The inertia constant of a power system is denoted by H, which is defined by the ratio of stored kinetic energy in mega joules at synchronous speed to rating of the machine in MVA [61].

That is, $H = \frac{\textit{Stored kinetic energy in megajoules at synchronous speed}}{\textit{Machine rating in MVA}}$

$$H = \frac{\frac{1}{2}J\,\omega_{sm}^{2}}{G_{mach}} \qquad (2.1)$$

Where, H= inertia constant in MWs/MVA,

J= moment of inertia in kg-m^2 of the rotating mass.

ω= nominal speed of rotation in rad/s

G_{mach} = MVA rating of the machine.

If the torque produced by a machine's prime mover does not match the torque produced by the generator magnetic fields the machine will accelerate or decelerate. A basic equation relating torque to acceleration is:

$$T_a = J\frac{d\omega}{dt} \text{ N-m} \qquad (2.2)$$

Where, T_a= Accelerating Torque

J= moment of inertia in kg-m^2 of the rotating mass.

ω= nominal speed of rotation in rad/s

Substituting the value of J from equation (2.1)

$$T_a = \frac{2H\,G_{mach}}{\omega^2}\frac{d\omega}{dt} \text{ N-m} \qquad (2.3)$$

If rated torque is defined as rated G_{mach} divided by square of rated frequency then equation (2.3) can be converted into per unit accelerating torque:

$$T_{a\,pu} = 2H\frac{d\omega_{pu}}{dt} \quad \text{pu} \qquad (2.4)$$

This can be solved for rate of change of frequency (ROCOF)

$$\frac{d\omega_{pu}}{dt} = \frac{T_{a\,pu}}{2H} \qquad (2.5)$$

Unless frequency drifts far from the base frequency we can approximate per unit torque as being the same as per unit power, so T_a may be replaced by P_a and similarly ω_{pu} can be replaced by f_{pu}, hence the equation will be

$$\frac{df_{pu}}{dt} = \frac{P_{a\,pu}}{2H} \tag{2.6}$$

The significance of the above equation is that it is used to determine the ROCOF of the system and $P_{a\,pu}$ is defined as follows [62]

$$P_{a\,pu} = \frac{\Delta P}{P_{gen}} \tag{2.7}$$

Hence,

$$P_{a\,pu} = \frac{P_{gen} - P_{load}}{P_{gen}} \tag{2.8}$$

Where, ΔP = Megawatt of load addition or generation lost.

P_{gen}= Generation of the system

P_{load}= Connected load of the system

The solution of the differential equation (2.6) can be written as:

$$f(t) = f_0[1 + (\frac{P_{a\,pu}}{2H})t] \tag{2.9}$$

Where, f_0= Initial Frequency (System Frequency)

This equation can be solved for the time that it takes to reach a given frequency:

$$t(f) = \frac{\frac{f}{f_0}}{\frac{P_{apu}}{2H}} \tag{2.10}$$

The following figures shows the ROCOF for various combinations of $P_{a\ pu}$ and H and it is clearly depicted from the following figures that for a higher value of H the ROCOF will be lower.

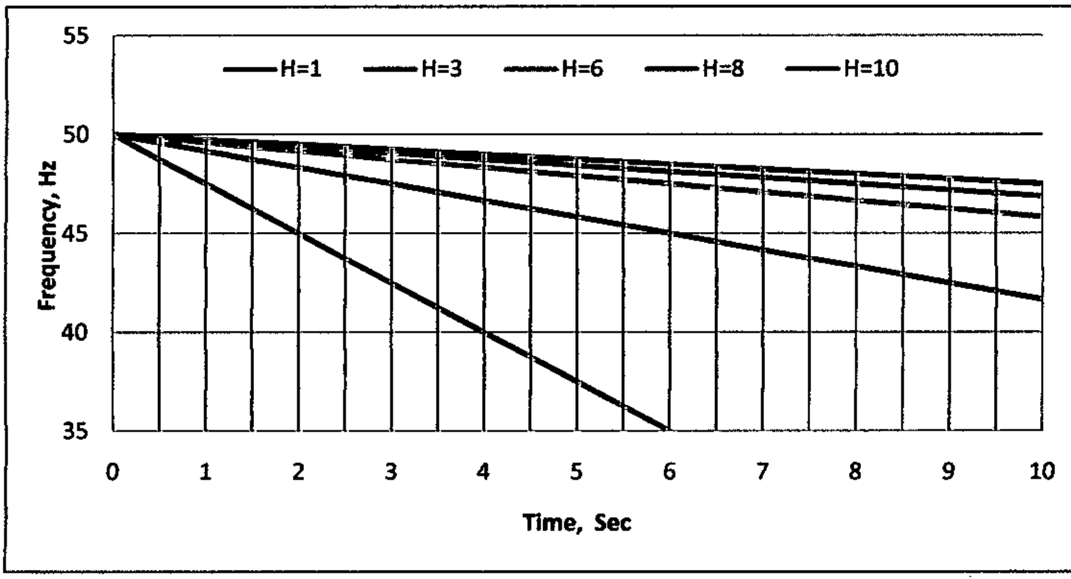

Fig. 2.2 ROCOF for different Inertia Constant of a System where P_a=0.10 pu.

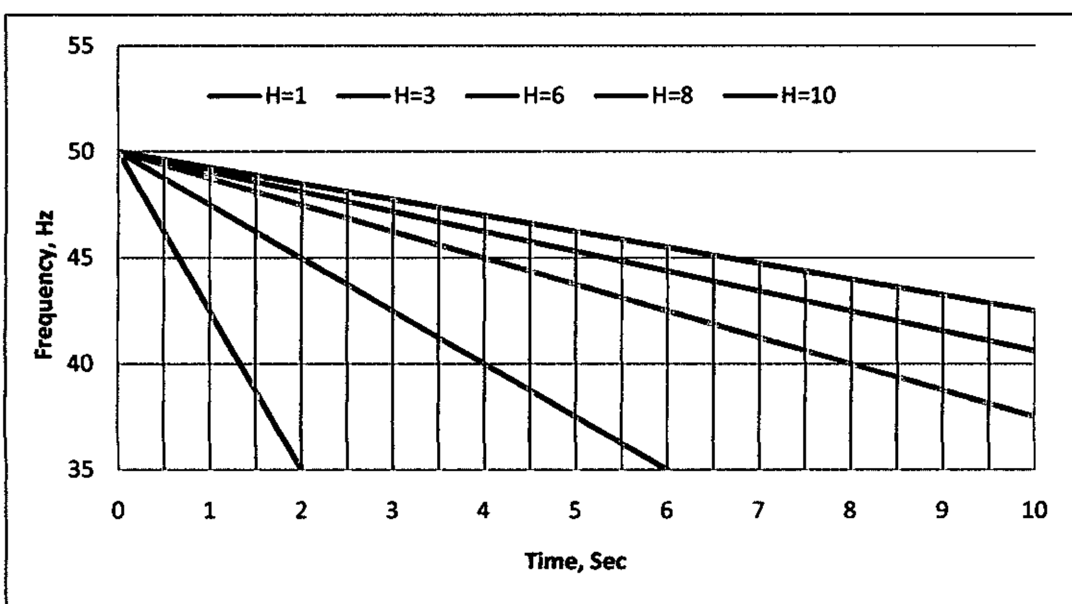

Fig. 2.3 ROCOF for different Inertia Constant of a System where P_a=0.30 pu.

The inertia constant H has a characteristic value or a range of values for each class of machines. Table 2.1 lists inertia constants of some typical machines [63].

Table 2.1 Inertia constant for different types of machines

Types of Machines	**Inertia Constant (H) in MJ/MVA**
Turbine Generator	
Condensing: 1800 r/min	9-6
3000 r/min	7-4
Non condensing: 3000 r/min	3-4
Waterwheel Generator	
Slow speed: <200 r/min	2-3
High speed : >200 r/min	2-4
Synchronous Condenser	
Large	1.25
Small	1.00
Synchronous Motor	
with Load varying from 1.0 to 5.0 and higher for heavy flywheels	2.00
Diesel Engine	1-3
Load, Motor	0.5-3

It is observed from Table 2.1 that the value of H is considerably higher for steam turbo generator than for water wheel generator.

For a multi machine system H constant of the overall system is defined by the following equation [54],

$$H_{system} = \frac{\sum H_i G_i}{\sum G_i} \tag{2.11}$$

Where, $\sum G_i = G_{system}$

H_i = H constant of the i-th machine.

G_i = the apparent power of the i-th machine.

Here the inertia constant of loads are included as well. The value of H for loads varies with type of load; though motors load have some inertia but resistive load do not have any inertia. From the above equation it can be easily depicted that with the increase of number of machines the value of inertia constant will be increased hence the stability of larger system will be higher.

2.3.2 Importance of Inertia Constant

Because of lower inertia constant H of diesel engine generation plants shows lower system stability than other system when any types of disturbances occur in the system. When the diesel engines generation plants are replaced with steam turbine plants the systems shown more stability because of higher inertia constant of newer types of machines. Based on the results of the study and practical facts presented in literature [53] it is apparent that the system frequency stability is very much dependent on the overall H constant of the system.

The addition or installation of machines with higher inertia constant makes the system more stable in case of any physical disturbances. In the close recovery it was evident that the rate of change of frequency and frequency drop decreases with addition of machines with high inertia constant.

2.4 Conclusion

Under steady state condition of a power system the mechanical and electrical energy must be balanced but if the electrical load exceeds the supplied mechanical energy, the system frequency will fall. The rate of change of frequency (ROCOF) depends on the initial power mismatch and system inertia. The change of speed of the generator will continue until the mechanical power supplied to the transmission system is equal to the electrical demand.

Disturbances in an interconnected power system lead to frequency deviations in the grid. This initial reaction of the power system to a disturbance is called inertial response of the system. The so called inertia constant H describes then the characteristic of the inertial response, which has been discussed in this chapter. The bigger value of this constant refers the higher stability of the system.

Chapter 03

Islanding Techniques

3.1 Introduction

Islanding is the part of a power system consisting of one or more power sources and load that is separated from the rest of the system for some period of time,, that means islanding is a situation where a portion of the utility system that contains both loads and generation sources is isolated from the remainder of the utility system but remains energized. The islanded system may be load rich or generation rich; in case of load rich islanded system load shedding scheme is required and for generation rich system generation must be reduced to balance the system load to generation.

3.2 Why Islanding is Necessary?

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 emergency load shedding schemes are applied to prevent the degradation of system frequency; the objective is to balance the load and generation of the system. But when the rate of change of frequency become higher and the system cannot be stabilized by load shedding scheme then an integrated power system has been disintegrated into different zones for the higher service reliability and to prevent system blackout. Additionally, for maintenance purpose some portion of an integrated system has to be separated sometimes to provide continuous supply of energy to important and critical loads.

In order to facilitate investigation of power system security and design of appropriate control strategies, power systems can be conceptually classified into five operational states: Normal, Alert, Emergency, In Extremis, and Restorative [13]. Fig. 3.1

illustrates these operating states and the transitions which can take place between states.

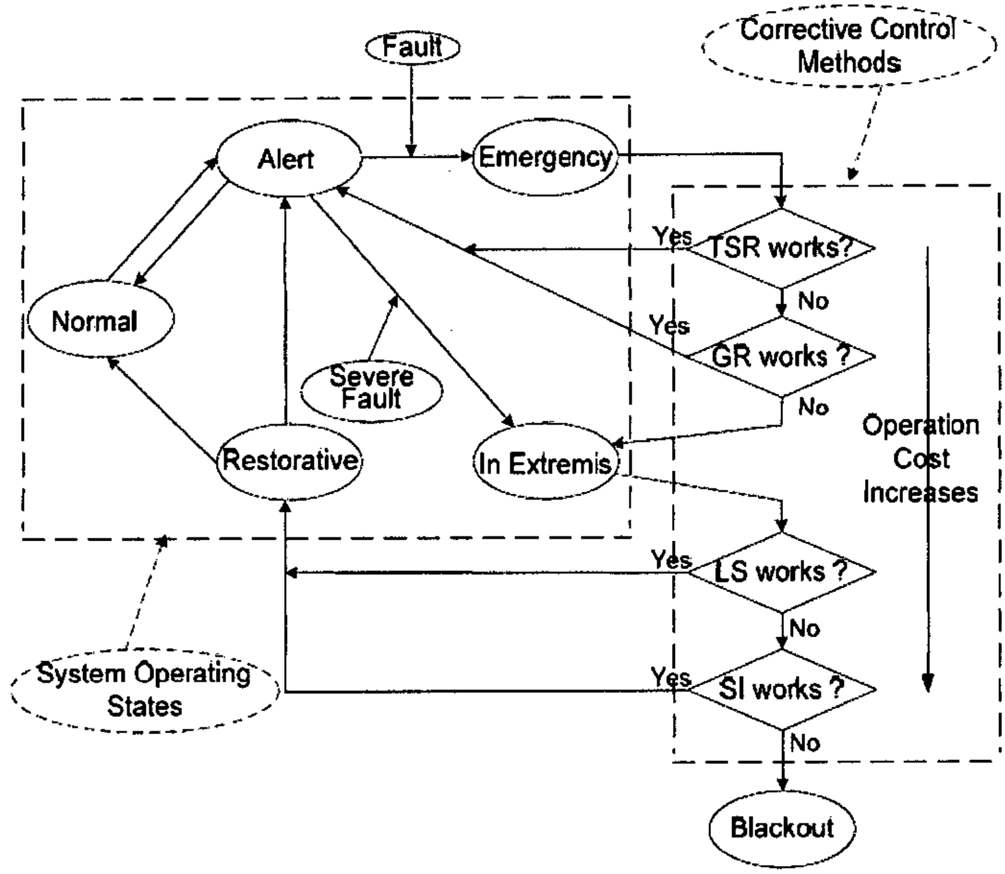

Fig. 3.1 Power system operating states and relative corrective control strategies [13]

Controlled or planned islanding of power system is the last defense line against wide–area blackout of interconnected power networks. When a system is affected with severe instability problem, and emergency control fails to bring the faulted system back to the normal state, an islanding strategy is executed and splits the interconnected power network into several islands by disconnecting selected transmission lines.

3.3 Types of Island

When an integrated electrical power system has been disintegrated to separate islands through finding the weak link/links between different zones and tripping the connection between them, different types of island may form. According to load and generation size the islands may be load rich or generation rich. To match load with generation a certain portion of load must shed in a load rich island whereas some generators should be shut down in a generation rich island.

According to the load size, islands are categorized in three groups such as: small (<100 MW), medium (100~500 MW) and large island (>500 MW).

Islanding may also be classified as inadvertent or intentional. The intentional islanding is preferably done with a minimal load flow to/or from the main grid but inadvertent islanding occurs during a heavy load flow to/or from the main grid necessarily causes an unbalance in production and load.

3.4 Islanding Detection Methods

Traditionally islanding detection methods are divided into two major subgroups such as: passive and active detection methods. There are some other islanding detection methods such as hybrid detection method which combines both active and passive methods, utility detection method is based on installed specific equipment and communication method is based on communication between grid and DGs.

3.4.1 Passive Detection Method

Locally available quantities such as voltage or frequency are used to detect island in passive islanding detection method. The quantities are derived from the high voltage level using voltage and current transformers, which is fed the detecting devices. These detection methods do not affect the waveform of the high voltage. These are beneficial since it does not raise any power quality issue such as voltage dips. Followings are the some common passive islanding detection methods:

- Over/under Voltage
- Over/under Frequency
- Voltage Phase Jump
- Rate of Change of Power
- Rate of Change of Frequency
- Detection of Voltage Harmonics
- Detection of Current Harmonics

3.4.1 Active Detection Method

Active islanding detection methods either try to manipulate the voltage or the frequency at the connection point or the manipulation is a result of measurements used by the method. The active methods have in general a better reliability than the passive methods. Followings are the some common active islanding detection methods:

- Impedance Measurement
- Detection of Impedance at a Specific Frequency
- Slip-mode Frequency Shift
- Frequency Bias
- Sandia Frequency Shift
- Sandia Voltage Shift
- Frequency Jump

3.4.3 Communication and Utility Detection Method

Communication detection methods have been considered as most expensive methods. This is however changing when new communication channels can be utilized, traditionally only utility owned wires and channels subscribed from public telephone companies have been considered. Today radio transmitting (FM or AM) and optic fibers can be added to the list. Internet with TCP/IP makes it possible to communicate the same information to a wide range of equipment. The inter dependability between the communication channel and the power system must be considered. Followings are the some common communication and Utility islanding detection methods:

- Impedance Insertion
- Power Line Carrier Communications
- Supervisory Control and Data Acquisition

3.5 Different Techniques of Islanding

Islanding is an approach to prevent blackout in extreme abnormalities. But the question is where the network should be disconnected to form an island. The formation of islands is not unique. The widely used islanding formation techniques are: graph partitioning, generator grouping, minimul cutest enumeration, Newton power flow technique, OBDD technique and so on.

When an integrated system is splitted into two islands, each load bus belongs either to one island or the other. Finding the weak link/links between different zones of power system is the target of these islanding approaches. For a radial nature power system it's easier to find the bus/buses where the system can be disintegrated by carefully inspecting the mismatches between loads and generations of different zones.

3.6 Conclusion

Intentional Islanding can support local supplies to critical and important customers in the event of network failure or schedule maintenance, thus increasing the system reliability, reduces outage cost by providing an alternative power source and hence increase the revenue.

Though islanding is the final resort at the time of extreme abnormality but as it is a very weak system the equipment and devices may fail due to unsuitable power quality. Well planned protection and operation schemes are required for intentional islanding operation because the islanding operation is more complicated than normal operation; generator may be damaged due to inappropriate operation and safety of the line crew is one of the major concerns during islanding operation. Additionally, squirrel case induction generator cannot operate during islanding operation but only synchronous generator.

Chapter 4

Simulation Technique

4.1 Introduction

Bangladesh Power System (BPS) is considered for investigating the impacts of an island with various features with a view to develop a general principle of islanding so that the created islands have positive contribution towards the stability of the global system as well as stability of island individually.

Two islands named Dhaka and Khulna-Barisal region have been simulated for various phenomena inside the islands such as sudden load addition, generation loss and combined effect of both load addition and generation loss. The simulated results are then compared to develop a principle of islanding during disintegration of system to stabilize a faulted power system.

4.2 Brief Description of BPS

Bangladesh power system (BPS) is a small system with a peak demand of around 7000 MW whereas the install capacity is about 6700 MW. Geographically it is divided into two parts by the rivers Padma and Jamuna, known as east zone and west zone. The east zone and west zone are interconnected through two tie lines, known as east west interconnection-1(EWI-1) and east west interconnection-2(EWI-2). Most of the power plants of BPS have been installed in east zone as the main fuel for electricity generation in Bangladesh is natural gas and most of the sources of this fuel are located in east zone; hence the total generation of this part is greater than that of load demand. On the other hand the power plants of west part are mainly based on coal and oil; the total generation is lower than load demand for this part. So the tie lines EWI-1 & EWI-2 is generally to transfer electricity from east zone to west zone.

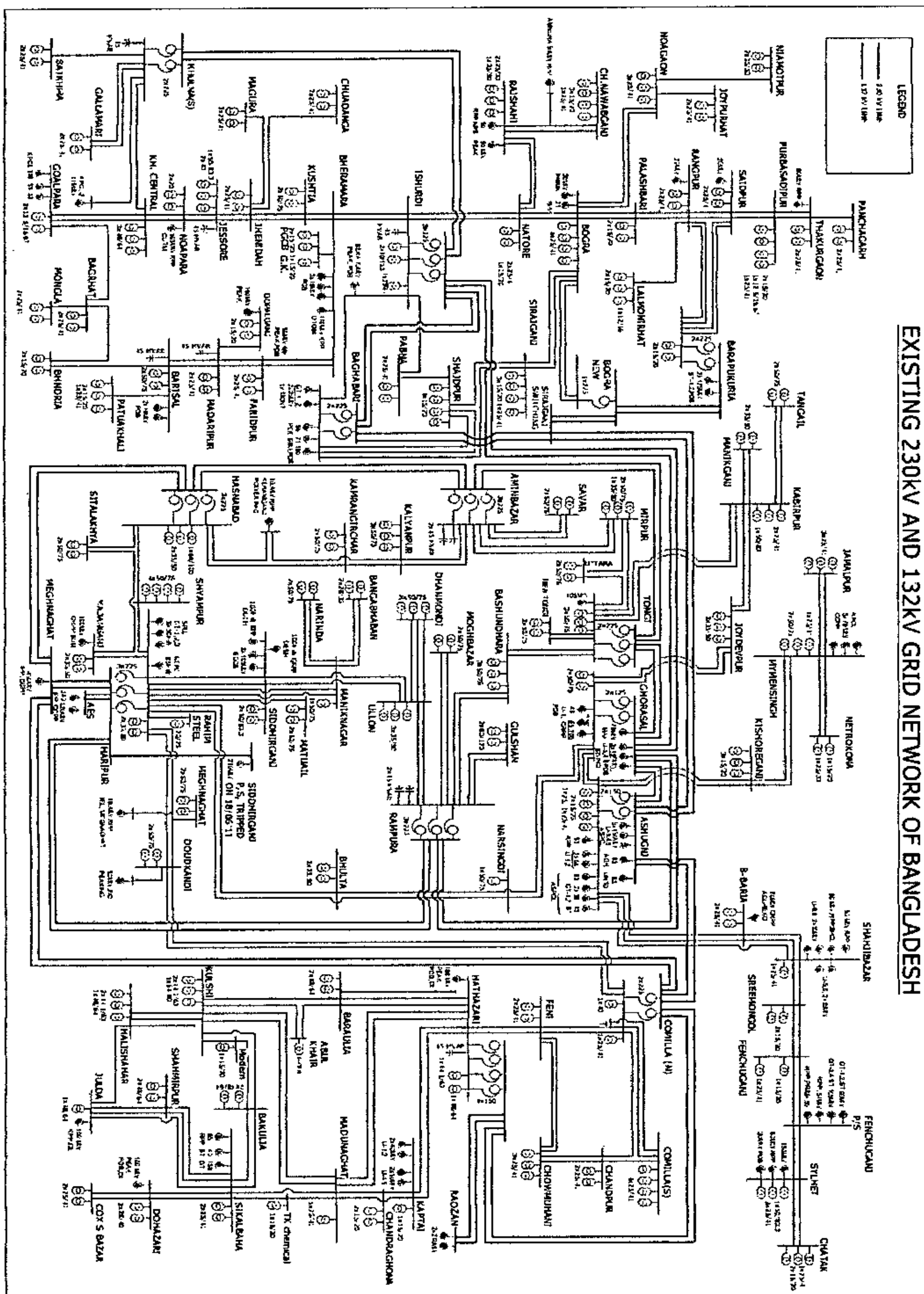

Fig. 4.1 Existing 230 kV and 132 kV grid network of BPS [64].

Electricity is being supplied to the whole country through the transmission system of BPS and it has formed an integral grid of two voltage levels of 132kV and 230 kV. The existing 230 kV and 132 kV grid network of BPS has been shown in Fig. 4.1[65]. BPS grid network on map is shown in Appendix B.

The BPS grid network is inherently radial in nature and divided into six regions [5]-[6]. The status of different regions (islands) in terms of generation capacity and loads are different; four of these islands are load rich and rest two are generation rich. Fig. 4.2 shows the radial nature structure of BPS which clearly shows the regions are like islands and connected radially to Dhaka region.

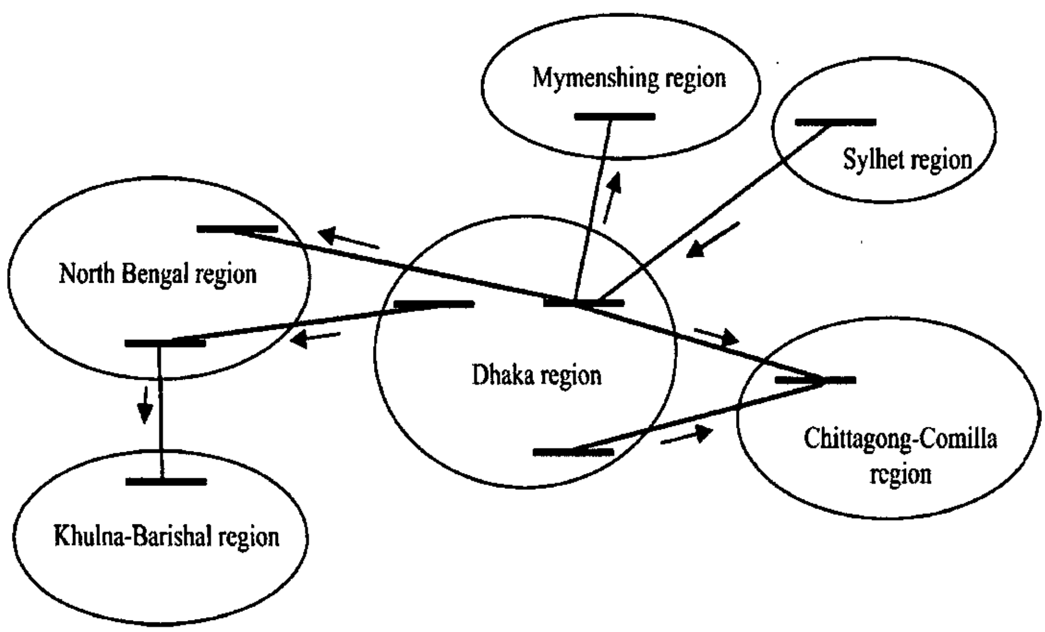

Fig. 4.2 Radial nature of Bangladesh Power System (BPS) [5]-[6]

The status of different islands of BPS in terms of generation capacity and sizes of loads of a typical day [65] is given in Table 4.1 and appendix A shows the load flow analysis of BPS. The table shows most of the islands are load rich and only two of them are generation rich. A load rich island is the one whose available generation is less connected load and generation rich island has more available generation than its load demand. Generator buses of these rich islands are connected to tie lines to supply power to the load rich regions.

Table 4.1 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**	---

4.3 Simulation Technique

Abnormal condition to a power system generally leads to fall of frequency and sometimes extreme abnormality leads to blackout of an integrated system. Though traditionally, interconnection standards avoid islanding operation but in case of emergency islanding can support local supplies to critical and important loads to improve the service reliability.

The usual solution to rescue the system from falling of frequency is the load shedding. However, in some cases the load shedding may be unnecessary as the system makes itself stable by providing additional input from its stored kinetic energy or from the spinning reserve or by lowering the system frequency within acceptable limit. In some cases, only load shedding cannot rescue the system from total collapse. In those cases, the system may be disintegrated into a number of islands.

BPS has been disintegrated into to six different islands; two of them are simulated for various impacts. The traditional and adaptive load shedding schemes are implemented through FS and FD relays respectively.

Different impacts of different sizes (in terms of MW) of islands such as maximum amount of load addition or generation loss for the stable operations of the islands without activating any relay have been studied. At the same time a frequency based auto load shedding scheme has been developed and percentage of load shedding amounts have been measured and compared for the islands in case of load addition, generation loss or for the combined effects of both load addition and generation loss. The scheme has been applied to Dhaka and Khulna-Barisal region to validate the effectiveness of the developed system.

4.3.1 Simulation Steps

The procedures that have been followed are:

Step 1: The load and the generation have been matched for both Dhaka and Khulna-Barisal regions.

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

Step 3: Percentage of load shedding to stabilize the islands 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 islands 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.

4.3.1 Relay Settings

The mostly used and popular load shedding scheme is the traditional load shedding as it is simple and does not require sophisticated relays. The traditional scheme sheds a certain amount of load when the system frequency falls below a certain threshold. If this load drop is sufficient, the frequency will stabilize or increase. If this first load shed is not sufficient, the frequency keeps on falling and reaches a second threshold, a second block of load is shed. This process is continued until the overload is relieved or all the relays have been operated. The values of the thresholds and the relative amount of load to be shed are decided offline, based on experiences and simulations. The frequency sensitive (FS) relay is used for this load shedding scheme.

The frequency decline rate means rate of change of frequency (ROCOF) is used as a measure of generation shortage in semi-adaptive and adaptive load shedding scheme. According to the value of ROCOF, a certain amount of load is shed. The speed at which the threshold is exceeded is checked and hence the amount of load shedding is measured: the higher the speed, the more load is to be shed. Usually, the measure of the ROCOF is evaluated only at the first frequency threshold; the subsequent one is being traditional. The ROCOF thresholds and the size of load blocks to be shed at different thresholds are decided offline on the basis of simulations and experiences. But the scheme adapts to the system disturbance as the actual amount of load blocks to be shed is decided depending on the rate of frequency change. The frequency droop (FD) relay is used for semi adaptive load shedding scheme.

The activation of different relays with appropriate time delays, i.e., relay settings is evaluated from trials and experiences. For the evaluation of these relay settings, all probable events, like different types of faults, withdrawal of different amount of generations, additions of different amount of loads and combined effect of both load addition and generation loss are simulated. The system frequency is monitored for the occurrence of each event and through appropriate load shedding the falling frequency is being stabilized within a range of target frequency. The appropriate amount of load shedding may be obtained from different trials and at the same time it should be noted that the target range of frequency, acceptable frequency range of normal operation, should be pre-defined from the experience of load dispatch center (LDC).

Table 4.2 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
*Relay operating time = 0.01 sec, * Relays have been connected to all load buses.		

Table 4.3 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
*Activation frequency threshold = 49.50 Hz, *Observation period = 10 cycles, * Relays have been connected to all load buses.		

In many cases the activation of FS relay is not enough to stabilize a system and for those cases the activation of FD relays is also required. The settings of FD relays are also evaluated through simulation of different events and then the amount of load to be shed. It should be noted that the amount of load shed is sensitive to the settings of FD relay. It may also be noted that in most of the cases, the operation of FS relay is required after the operation of FD relay. The FS and FD relay settings are given in Table 4.2 and Table 4.3 respectively.

4.4 Conclusion

First of all a power flow analysis of BPS has been performed then the integrated system has been splitted into six regions. Different impacts have been studied for a load rich and a generation rich island. After matching the generation and load for both islands different phenomena inside the islands have been studied and an auto load shedding scheme has been developed to stabilize the islands in case of disturbances i.e sudden load addition, generation loss and the combined effect of load addition and generation loss to the islands. Finally the simulation results have been compared with a view to recommend the sizes of island for a stable system operation and presented in chapter 5.

Chapter 5

Simulation Results

5.1 Introduction

BPS has been disintegrated into six islands; in terms of sizes of loads and generation capacity four of them are load rich and rest two are generation rich as discussed in previous chapter. Two different sizes of islands have been taken to compare different impacts on them. The Dhaka and Khulna-Barisal regions having about 3016MW, 607MW regular generations where the load sizes are about 2119MW and 729MW respectively.

Different phenomena such as load addition, load rejection and generation loss inside a load rich and a generation rich island have been studied and presented in section 5.2. After matching the load and generation for the islands, different impacts have been studied and compared and presented in section 5.3 with a view to develop a general principle of formation of islands during disintegration of system to stabilize a faulted power system.

5.2 Simulation Results of Load Rich and Generation Rich Islands

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. 5.1 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 loads become larger (case C) than the generation capacity because of load addition to the island; it will make the system unstable.

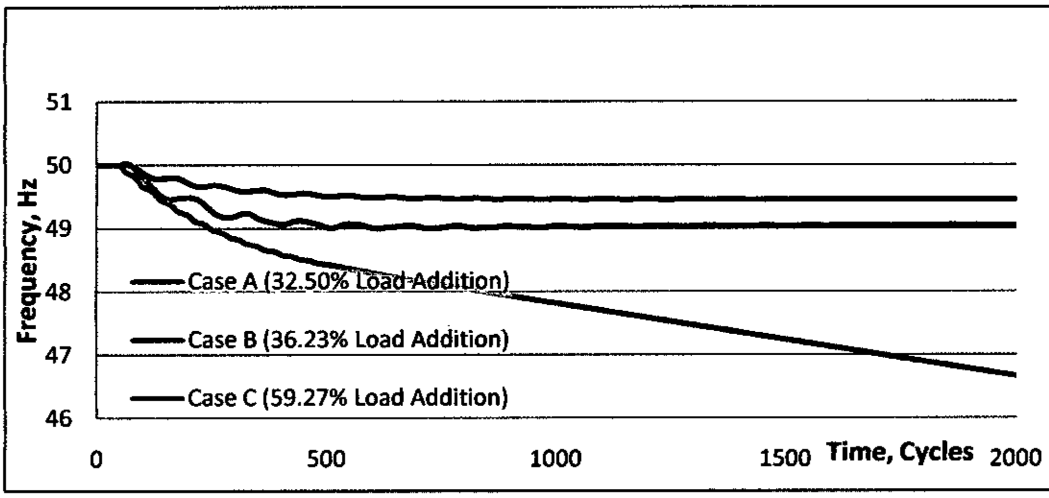

Fig. 5.1 Frequency response for load addition in a generation rich island

Fig. 5.2 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.

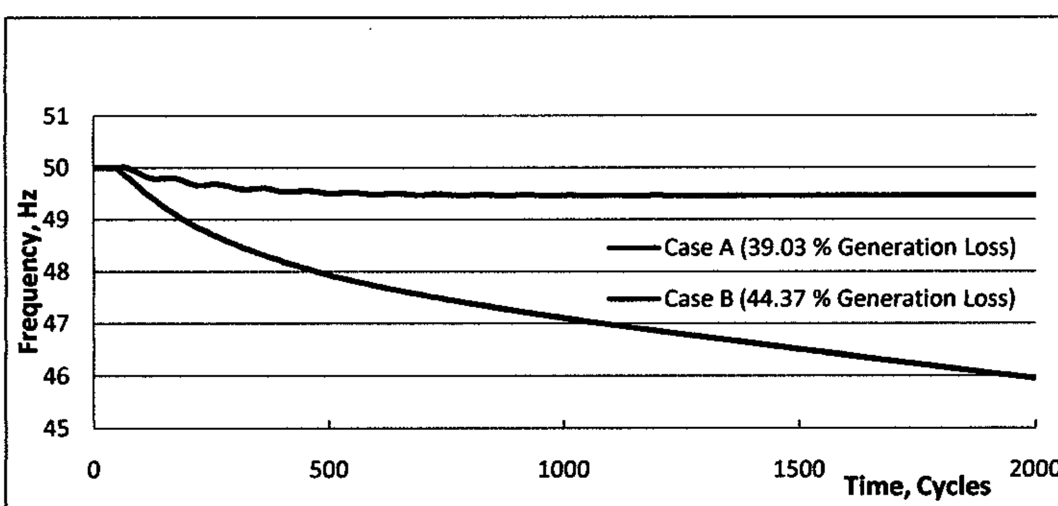

Fig. 5.2 Frequency response for loss of generation in a generation rich island

The island Khulna-Barisal is load rich as the generation capacity and load demand are 607 MW and 729 MW respectively. Case A, case B and case C of fig. 5.3 show the frequency responses of a load rich island for 36.61% (267 MW), 27.21% (198 MW) and 22.23% (162 MW) load rejection respectively. It is observed from figure that the higher the load rejection the larger the frequency raise.

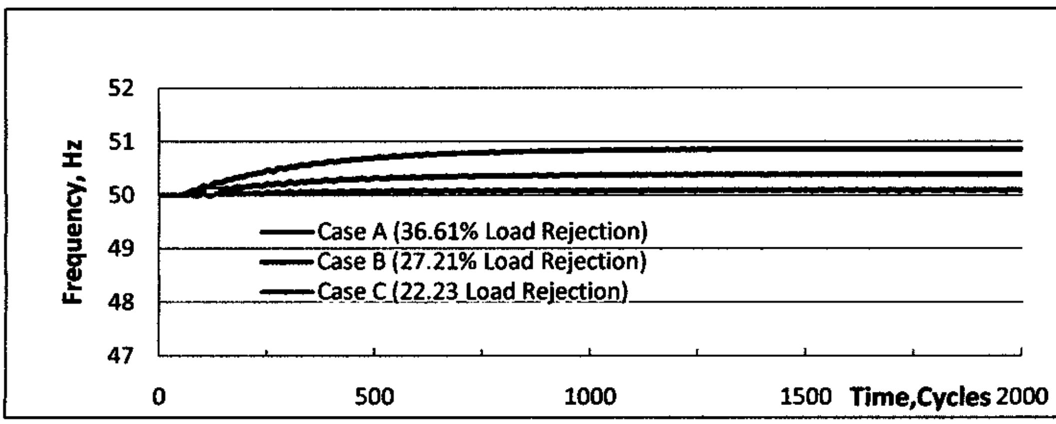

Fig. 5.3 Frequency response for load rejection in a load rich island

Frequency response characteristics of Khulna-Barisal Island for different amount of generation loss is shown in fig. 5.4; here case A shows the response for generation outage of 4.56 % (28MW) where case B and case C are for 7.82% (47 MW) and 11.79 % (72 MW) generation outage respectively. It is deduced from the figure that for higher amount generation loss the fall of frequency will be higher.

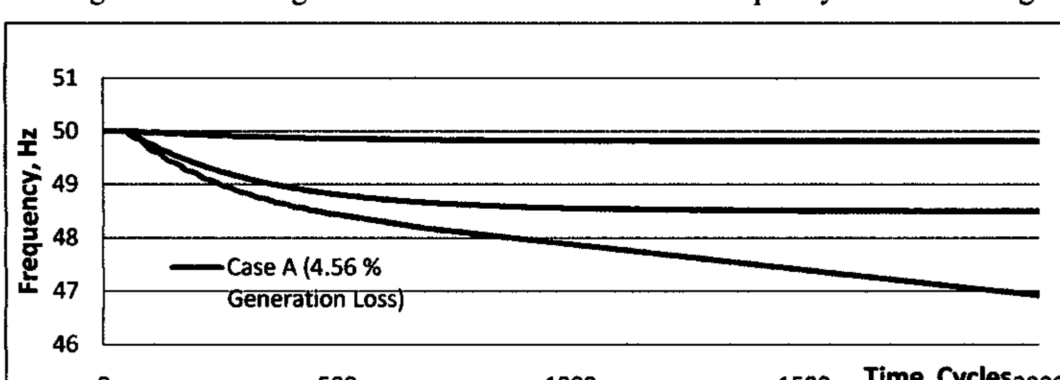

Fig. 5.4 Frequency response for loss of generation in a load rich island

5.3 Simulation Results of Different Sizes (in terms of MW) of Islands

The demand of electricity for a system does not remain constant and the system reacts according to the supply demand. Addition of extra load or loss of generation in a system leads to fall of system frequency whereas rejection of loads or activation of lost generator to a system leads to rise of system frequency. Before simulation the loads and generations are matched for Dhaka and Khulna Barisal regions. Different impacts have been studied inside the islands and compared with a view to develop a general principle of formation of islands during disintegration of system to stabilize a faulted power system.

5.3.1 Dhaka Region

5.3.1.1 System Response without activating any relay

After matching the generation and load demand for island Dhaka to 2100 MW; it has been simulated. Fig. 5.5 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.

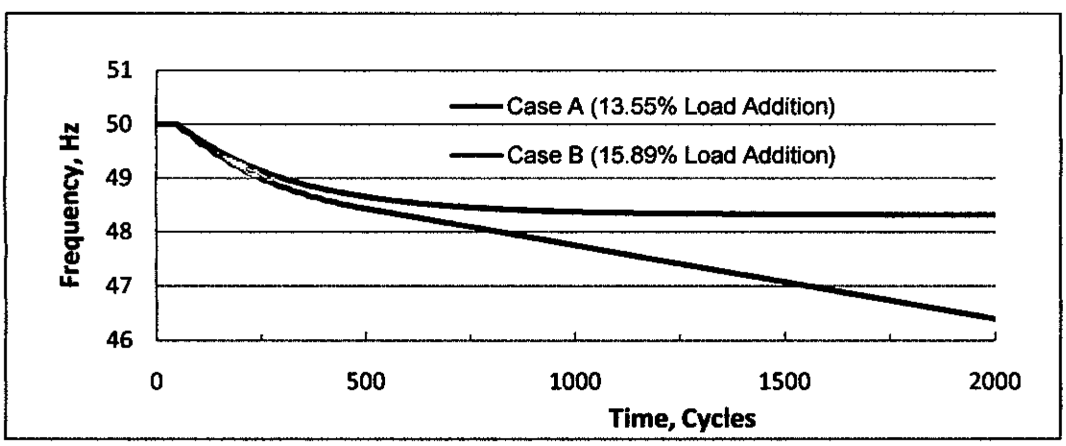

Fig. 5.5 Frequency response of Dhaka Island for load addition

The generators are connected to the system to fill up the demands of the load but the generation of a system will not remain same for the entire time span; because of disturbances to generators or for regular maintenance of generator leads to fall of generation. Fig. 5.6 shows the fall of frequency in Dhaka region (island) in case of generation loss when no relay is being activated to shed load; 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.

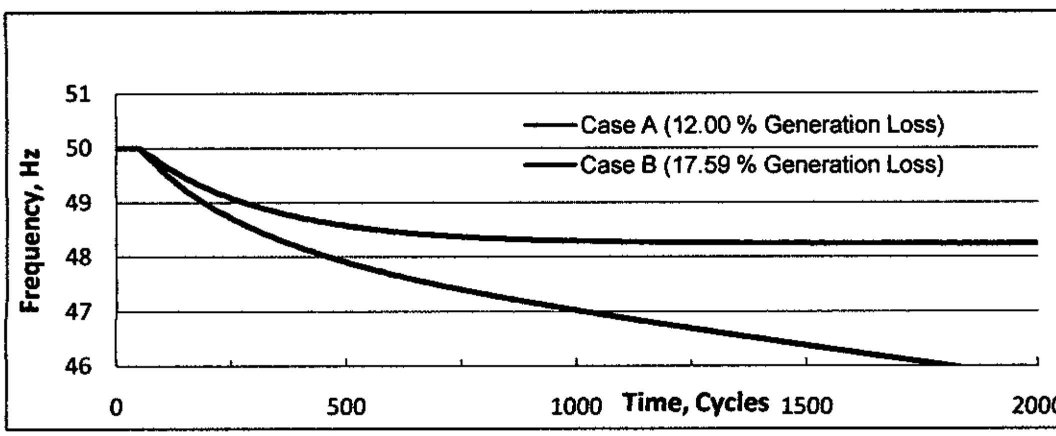

Fig. 5.6 Frequency response of Dhaka Island for generation loss

5.3.1.2 System Response activating both FS and FD relay

Auto load shedding scheme developed by using relays may stabilize the system for larger amount of load addition or generation loss. Fig. 5.7 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.

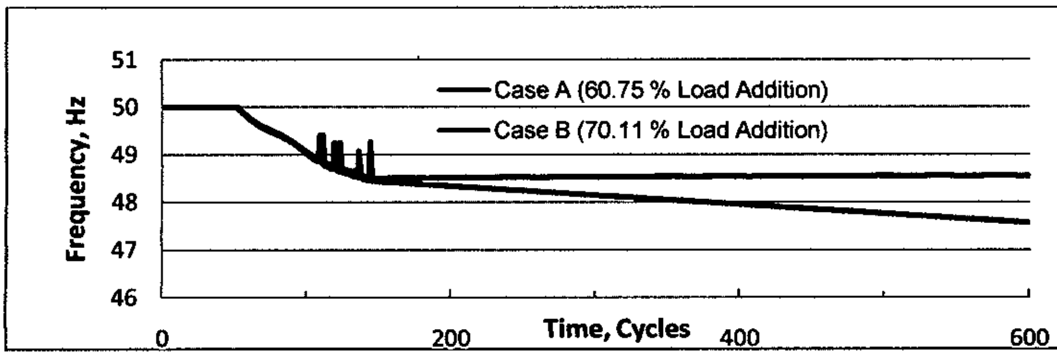

Fig. 5.7 Frequency response of Dhaka Island with only FS relay based load shedding.

An auto load shedding scheme has been applied using both FS and FD relays to Dhaka Island and FRC is shown in fig.5.8. 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.

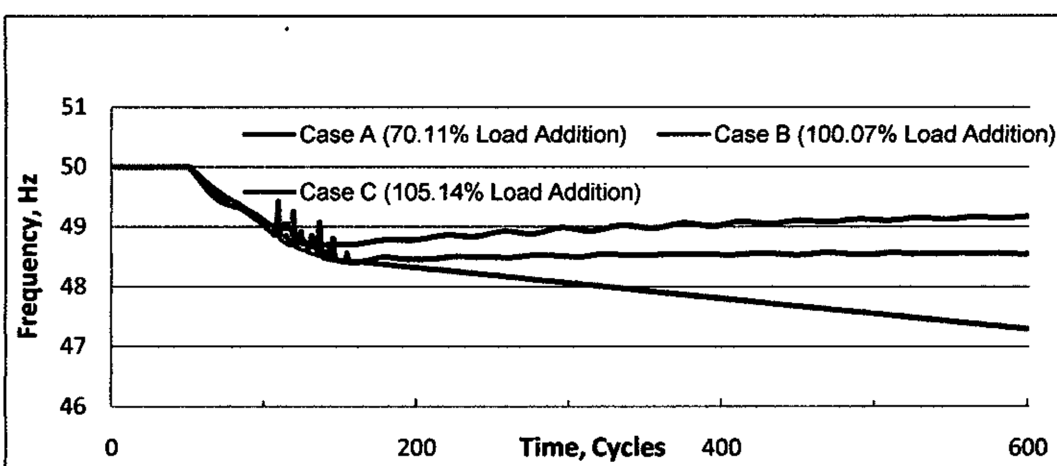

Fig. 5.8 Frequency response of Dhaka Island with both FS & FD relay based load shedding for load addition.

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. 5.9; case A refers system frequency remains within an accepted 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.

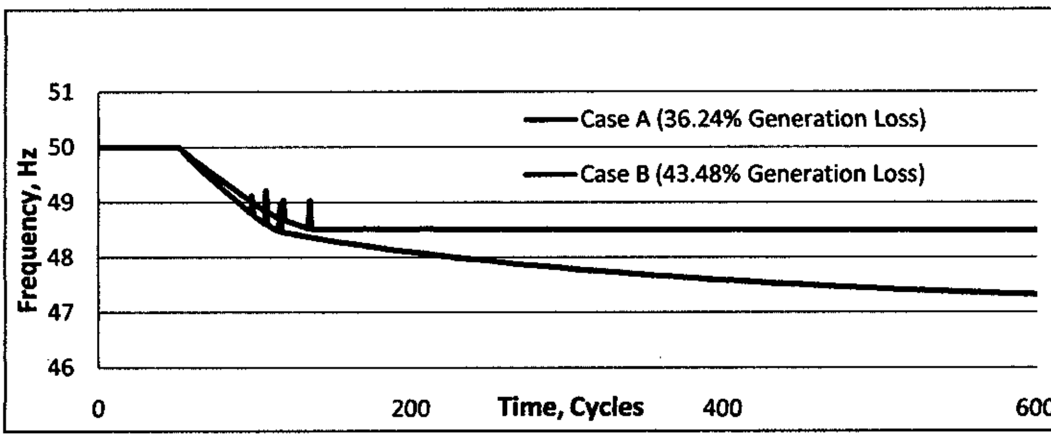

Fig. 5.9 Frequency response of Dhaka Island with only FS relay based load shedding for generation outage.

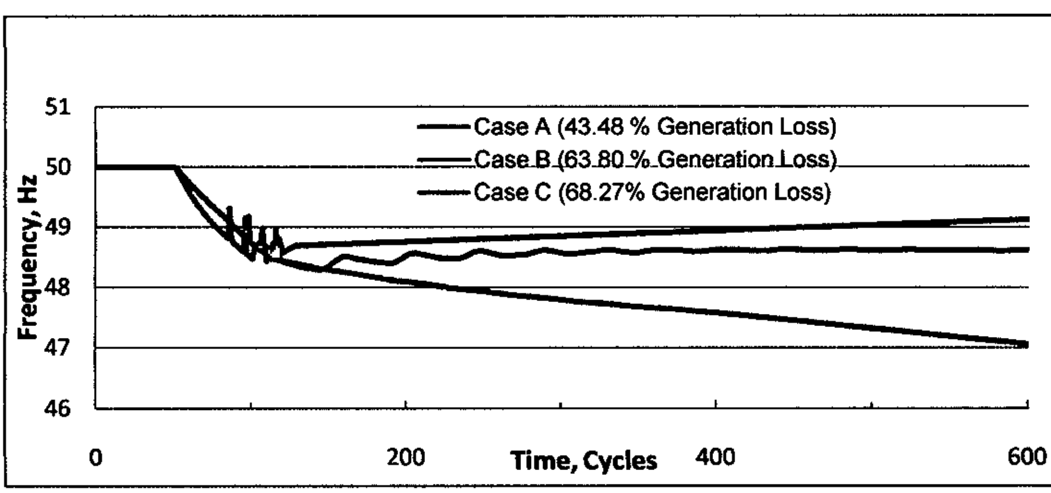

Fig. 5.10 Frequency response of Dhaka Island with both FS & FD relay based load shedding for generation outage.

Fig. 5.10 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.

5.3.1.3 System Response for cascading effect

To evaluate the performance of the developed auto load shedding scheme during combined effect of both generation loss and load addition is discussed in this section. Fig. 5.11 shows the performance of the load shedding scheme using only FS relay under some of the scenarios namely case A, case B, and case C.

Table 5.1 Percentage of load addition and generation loss for fig. 5.11

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

In brief, case A refers to sudden addition of load by 36.36 % and the cascaded generation outage of 16.90 %. Case B refers to sudden addition of load by 32.72 % and the cascaded generation outage of 19.40 %. Case C refers to sudden addition of load by 53.75 % and the cascaded generation outage of 26.60 %. The cases have been summarized in Table 5.1. The figure shows 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. 5.11 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.

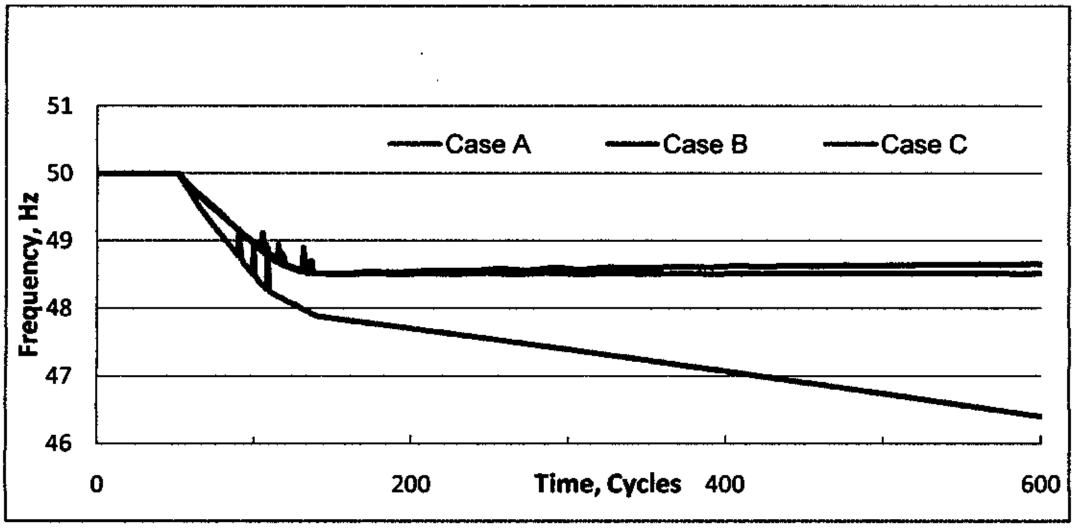

Fig. 5.11 Performance of load shedding scheme using only FS relay on Dhaka Island

Fig. 5.12 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. In brief, case A refers 53.75% load addition and cascaded generation outage of 26.60 %, case B refers 71.98 % load addition and 26.60 % generation outage, case C refers 60.52 % load addition and 35.60 % generation outage and finally the case D refers 70.95% load addition and 35.60% generation outage. The cases have been summarized in table 5.2. 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 5.2 Percentage of load addition and generation loss for fig. 5.12

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%

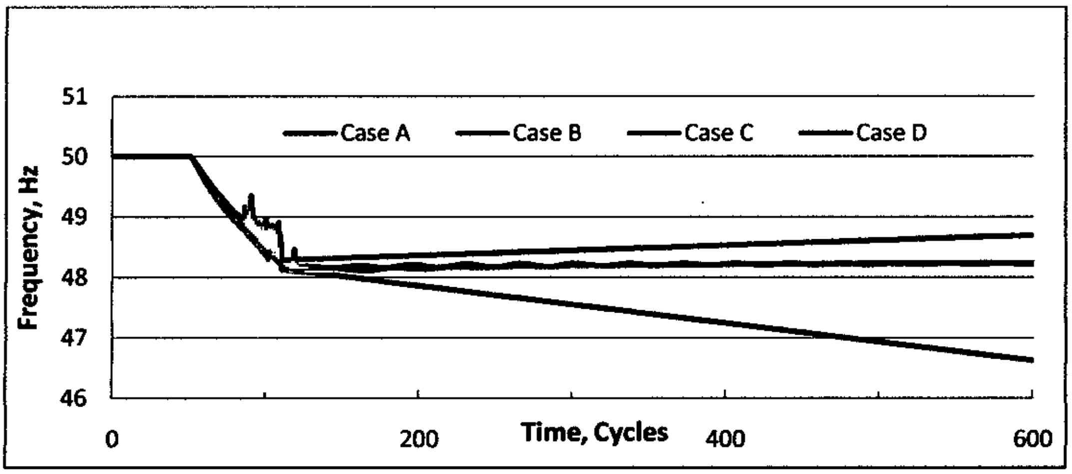

Fig. 5.12 Performance load shedding scheme using both FS & FD relays on Dhaka Island.

5.3.2 Khulna Barisal Region

5.3.2.1 System Response without activating any relay

After matching the generation and load demand for island Khulna-Barisal to 605 MW; it has been simulated for different transient phenomena. The demand of electricity for a system does not remain constant and the system reacts according to the supply demand. A sudden addition of load to an electric power system leads to fall of system frequency. Frequency responses for different amount sudden load addition to Khulna-Barisal Island have been simulated and shown. Fig. 5.13 shows the fall of frequency in Khulna-Barisal region (island) in case of load addition when no relay has been activated to shed load; case A refers system frequency remains within accepted range up to 11.74% (71 MW) load addition whereas case B refers in case of 15.89 % (96 MW) load addition the system frequency goes below the accepted range making the system unstable.

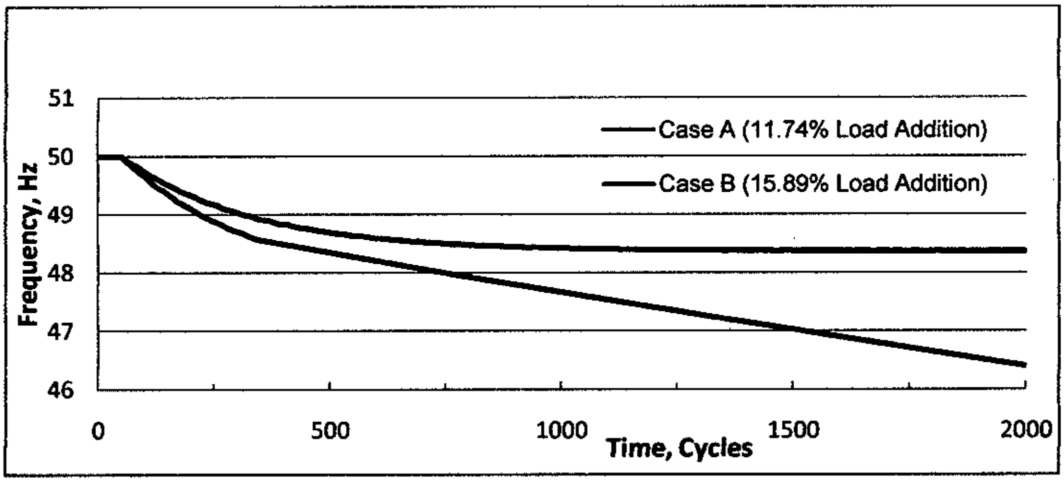

Fig. 5.13 Frequency response of Khulna-Barisal Island for load addition

The generators are connected to the system to fill up the system demand but the generations of a system will not remain same for entire time span; because of disturbances to generators or for regular maintenance of generator leads to loss of generation hence total amount of generation of a system is being changed. Fig. 5.14 shows the fall of frequency in Khulna-Barisal region (island) in case of generation loss when no relay is being activated to shed the connected load; case A refers system frequency remains within accepted range up to a generation loss of 11.69% (71 MW) whereas case B refers in case of 17.50% (106 MW) generation loss the system frequency goes below the accepted range and makes the system unstable.

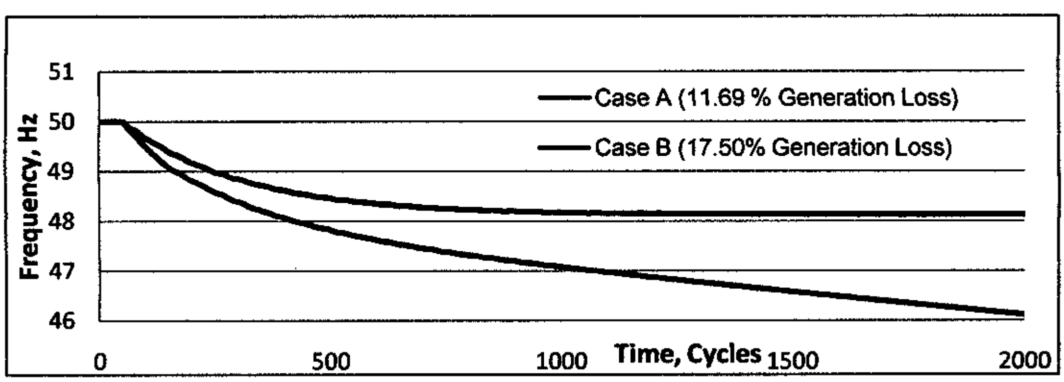

Fig. 5.14 Frequency response of Khulna-Barisal Island for generation loss

5.3.2.2 System Response activating both FS and FD relay

Auto load shedding schemes developed by using relays stabilize electric power systems for larger amount of sudden load addition or generation loss. Fig. 5.15 shows the frequency response of Khulna-Barisal 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 accepted range; case A refers system frequency remains within accepted range up to a load addition of 54.17% (328 MW) whereas case B refers in case of 60.69% (367 MW) load addition the system frequency goes below the accepted range making the system unstable.

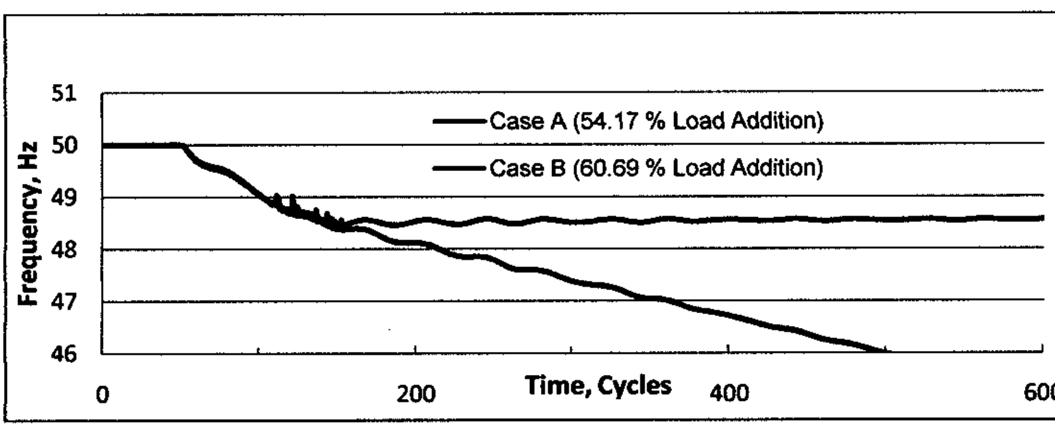

Fig. 5.15 Frequency response of Khulna-Barisal Island with only FS relay based load shedding for load addition.

Frequency response of Khulna-Barisal region (island) is shown in fig. 5.16 for sudden load addition where auto load shedding scheme based on both FS & FD relays has been applied to stabilize the system frequency within accepted range; case A and case B of fig. 5.16 refer system frequency remain within accepted range for 60.69% (367 MW) and 82.00% (496 MW) sudden load addition whereas case C clearly shows for 86.60% (524 MW) load addition the system frequency goes below the accepted range and hence the system become unstable.

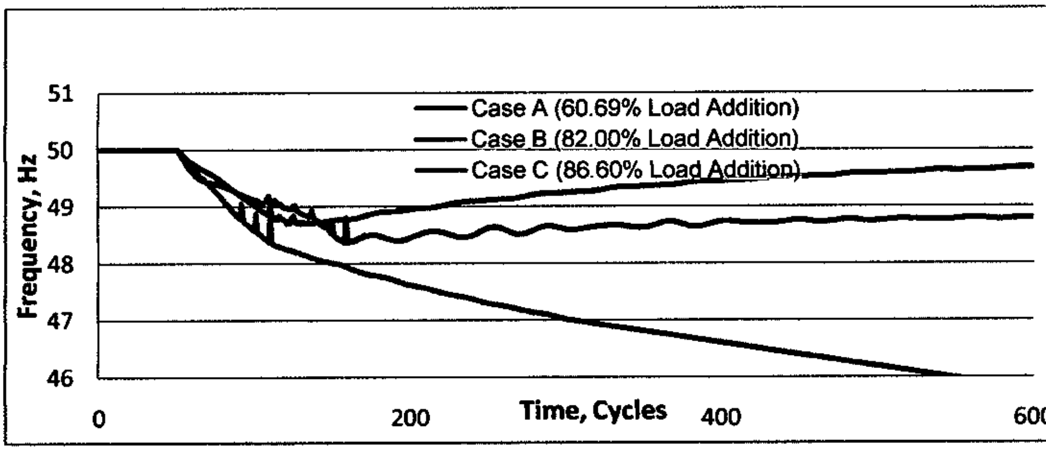

Fig. 5.16 Frequency response of Khulna-Barisal Island with both FS & FD relay based load shedding for load addition.

Frequency response of Khulna-Barisal (island) is shown in fig. 5.17 for generation loss where only FS relays based auto load shedding scheme has been applied to stabilize the system frequency. It is derived from the figure that for 28.03% (170 MW) generation outage the load shedding scheme stabilize the system frequency within accepted range on the other hand for 36.60% (221 MW) generation outage the system frequency goes below accepted range and the island become unstable.

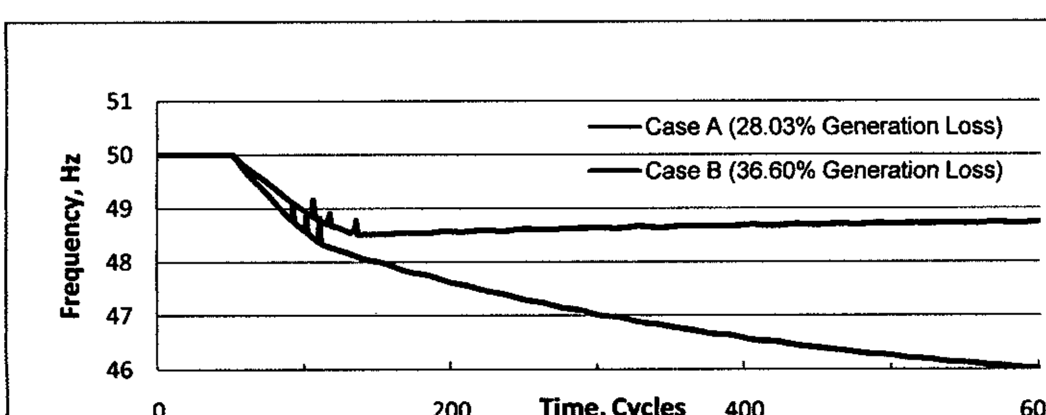

Fig. 5.17 Frequency response of Khulna-Barisal Island with only FS relay based load shedding for generation outage.

To stabilize system frequency within accepted range both FS and FD relay based load shedding schemes have been applied to Khulna-Barisal Island for generation outage and the simulated frequency response has been shown in fig. 5.18.Case A and case B refer system frequencies are within accepted range for 36.60% (221 MW) and 43.86% (265 MW) generation outages respectively. The remaining case C refers in for 54.82% (332 MW) generation loss the load shedding schemes could not stabilize the system as the system frequency falls below the accepted range.

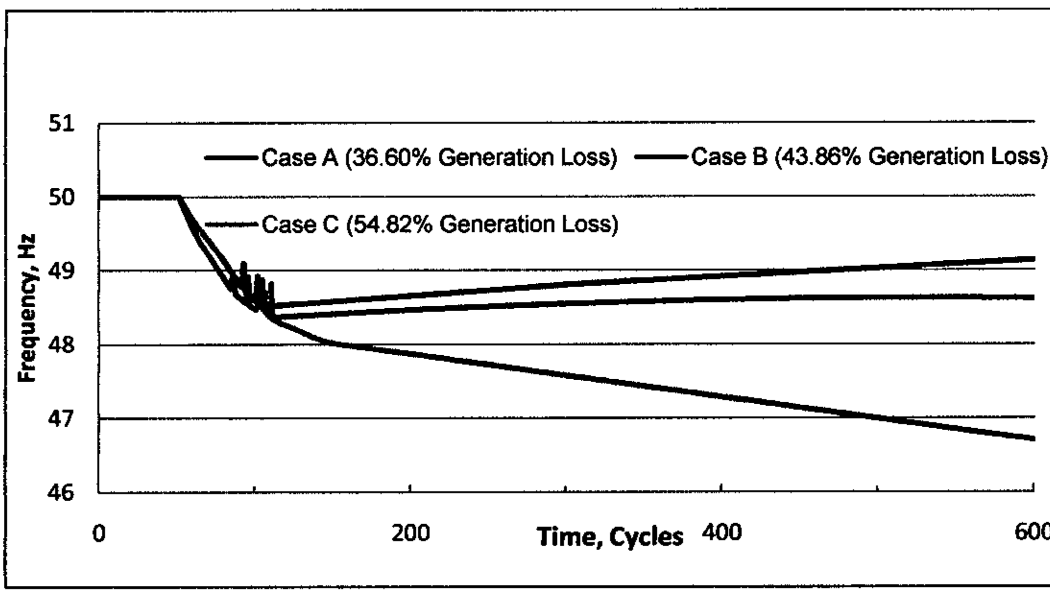

Fig. 5.18 Frequency response of Khulna-Barisal Island with both FS & FD relays based load shedding for generation outage.

5.3.2.3 System Response for cascading effect

To evaluate the performance of the scheme during combined effect of generation loss and sudden addition of load on Khulna-Barisal Island different combinations of load addition and generation lost are made and shown in table 5.3 and 5.4. Fig. 5.19 shows the performance of only FS relay based load shedding scheme for three different cases such as case A, case B, and case C on Khulna-Barisal Island. Here in brief, case

A refers 18.05 % load addition and 19.73 % generation outage, case B refers 22.55% load addition and 16.54 % generation outage and case C refers 12.05% load addition and 26.99% generation outage. The cases have been summarized in table 5.3. It is observed from the figure that for cases A and B the load shedding scheme stabilizes the system by maintaining the system frequency within acceptable range. On the other hand system frequency goes beyond the accepted range making the system unstable which is shown in case C.

Table 5.3 Percentage of load addition and generation loss for fig. 5.19

Case	Case A	Case B	Case C
Load Addition	18.05%	22.55%	12.03%
Generation Loss	19.73%	16.54%	26.99%

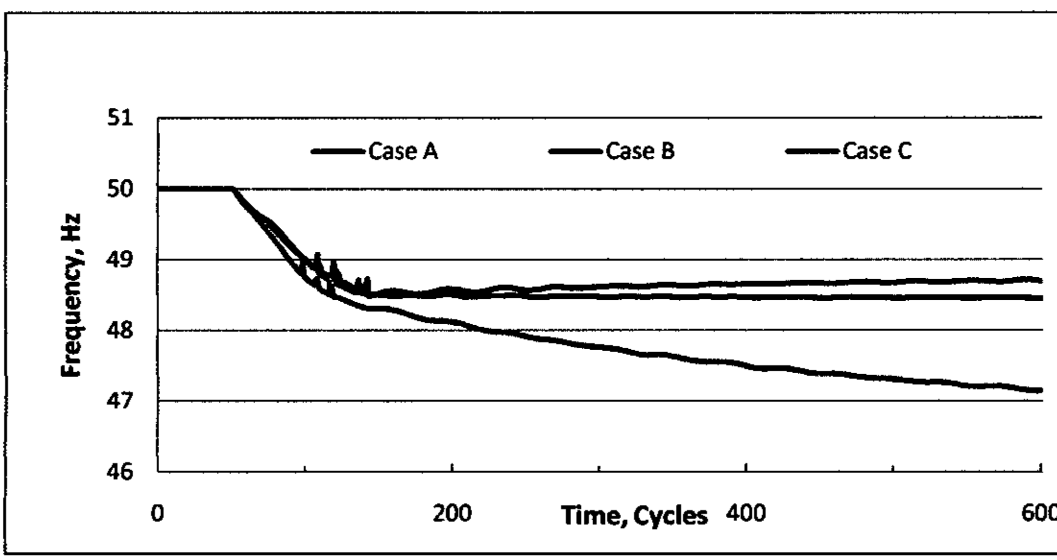

Fig. 5.19 Performance of load shedding scheme using only FS relay on Khulna-Barisal Island

The fig. 5.20 shows the performance of the load shedding scheme using both FS and FD relays under some other combination of load addition and generation loss on

Khulna-Barisal Island. Different combination such as case A refers 12.03% load addition and 26.99% generation outage, case B refers 36.09% load addition and 26.99% generation outage, case C refers 22.56% load addition and 35.56% generation outage and case D refers 30.87% load addition and 35.56% generation outage to the system. The cases have been summarized in table 5.4. It is clear from the figure that for cases A, B and C auto load shedding scheme maintain the system frequency within accepted range and hence the system become stable. But for case D as the system frequency falls below the threshold the system becomes unstable.

Table 5.4 Percentage of load addition and generation loss for fig. 5.20

Case	Case A	Case B	Case C	Case D
Load Addition	12.03%	36.09%	22.71%	30.87%
Generation Loss	26.99%	26.99%	35.56%	35.56%

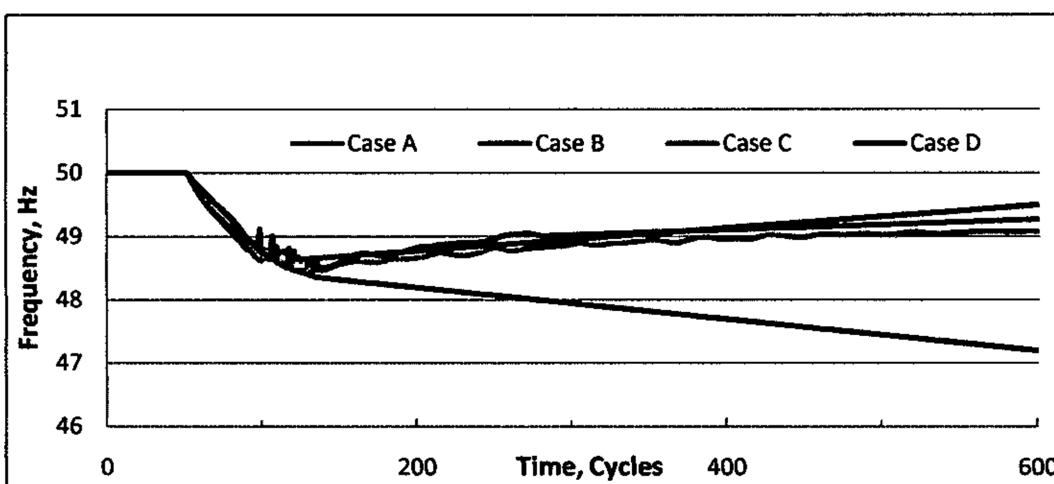

Fig. 5.20 Performance of load shedding scheme using both FS & FD relays on Khulna-Barisal Island

5.3.3 Comparison of simulated results

5.3.3.1 Islanding operations without using relay

The previous two sections of this chapter discussed the frequency responses for a load rich and a generation rich island as well as for different sizes of islands (large and small) when various transient phenomena were applied to the systems. The impacts of different sizes of islands will be compared in this section. Fig. 5.21 shows without activating any relay based load shedding 13.55% (284 MW) loads can be added to Dhaka region (Case A) where the percentage of load addition for Khulana-Barisal region (Case B) is 11.74% (71 MW). The result refers the larger islands can be operated in stable condition for larger percentage of sudden load addition.

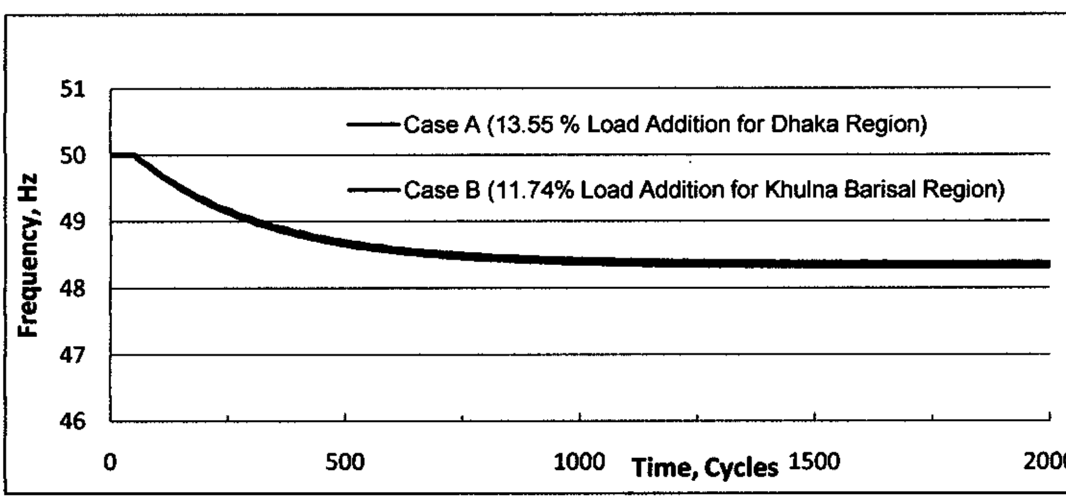

Fig. 5.21 Load addition comparison for different sizes of island without activating any relay

The fig. 5.22 shows without activating relay the Dhaka region (Case A) can be operated within acceptable frequency when 12.00% (252 MW) are forced to be shut down where the percentage of generation outages for Khulana-Barisal region (Case B) for system operation in acceptable frequency range is 11.69%(71 MW). It is observed from the result that larger islands can operate in stable condition for larger percentage of generation outages than smaller island.

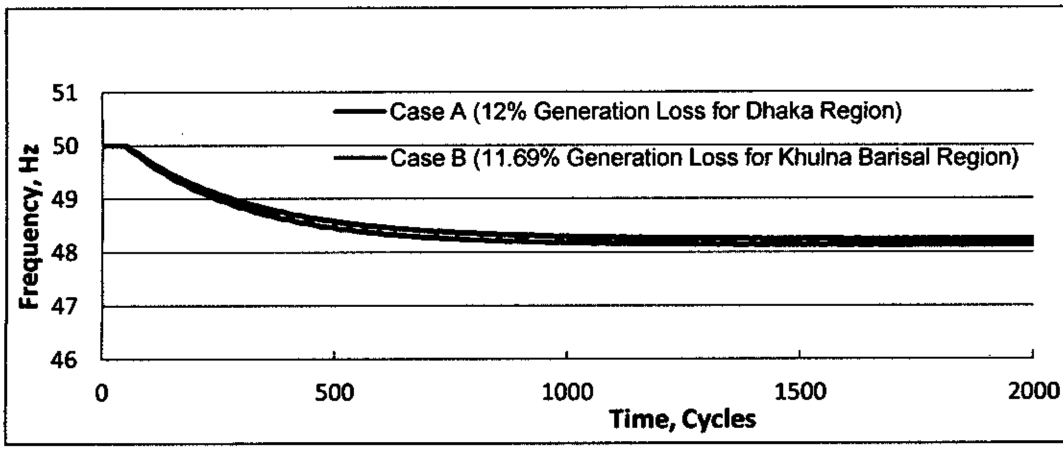

Fig. 5.22 Generation loss comparison for different sizes of island without activating any relay

5.3.3.2 Auto load shedding using relays to compensate load addition

The following two figures fig. 5.23 and fig. 5.24 show the maximum amount of load that can be added to the islands when auto load shedding scheme based on FS and FD relays are applied for stable operation of different sizes of islands.

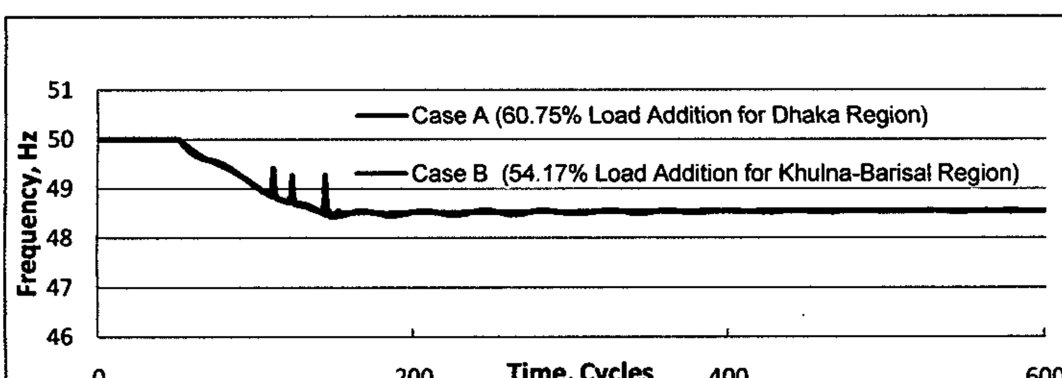

Fig. 5.23 Comparison of load addition when only FS relay based load shedding scheme applied on different sizes of islands.

Fig. 5.23 shows when traditional load shedding scheme based on only FS relays is applied to different sizes of islands the Dhaka Island and Khulna-Barisal Island can maintain their stable operation for 60.75%(1276 MW) and 54.17% (328 MW) load addition respectively. The fig. 5.24 shows for a stable system operation in Dhaka region up to 100.07% (2101 MW) and in Khulna-Barisal region up to 82.00 % (496 MW) load can be added while both FS and FD relay based load shedding schemes are applied to the islands. Both of the results comprise larger islands can add larger loads for a stable system operation as the larger island has greater inertia than smaller island.

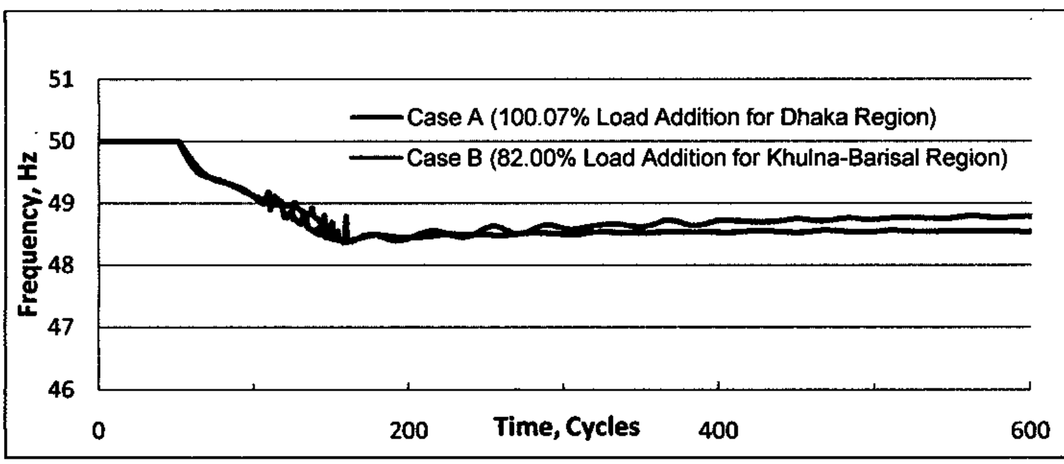

Fig. 5.24 Comparison of load addition when both FS & FD relay based load shedding schemes applied on different sizes of islands.

5.3.3.3 Auto load shedding using relays to compensate generation loss

Fig. 5.25 and fig. 5.26 show the maximum amount of generation losses for which different sizes of islands can maintain their stable operation while different types load shedding schemes are applied to the systems. It is observed from the fig. 5.25 that the island Dhaka can operate its stable operation for 36.24 % (761 MW) and the island Khulna-Barisal for 28.03% (170 MW) generation loss; here only FS relay based load shedding scheme is applied. If the generation outage goes beyond the specified percentage the islands will be unstable.

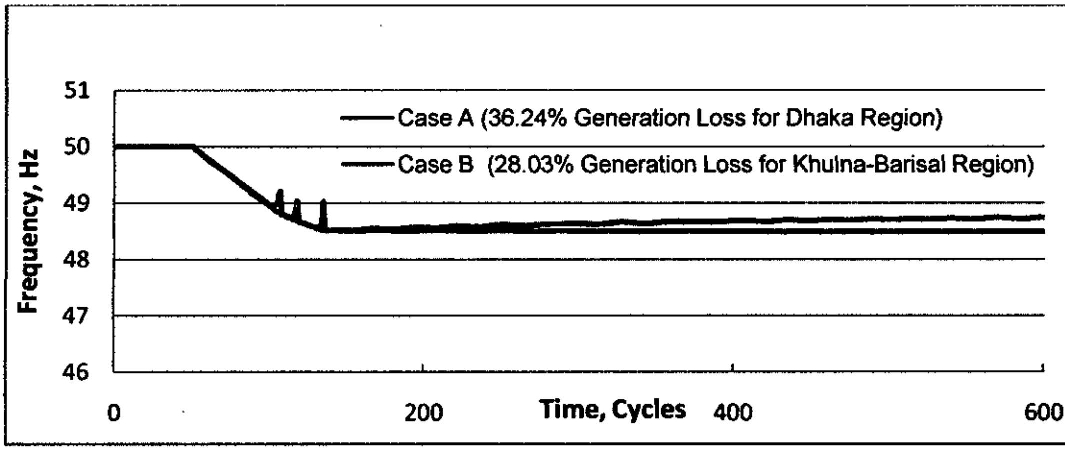

Fig. 5.25 Comparison of generation outage when only FS relay based load shedding scheme applied on different sizes of islands.

It is deduced from the fig. 5.26 that larger island can maintain its stable operation for bigger amount of generation outage as it has greater inertia constant than smaller island. Case A of the figure shows Dhaka Island can be operated within acceptable range of frequency for 63.80% (1340 MW) and Khulna-Barisal Island (case B) for 43.86% (265 MW) generation loss when both FS and FD relays based load shedding schemes are applied to the islands.

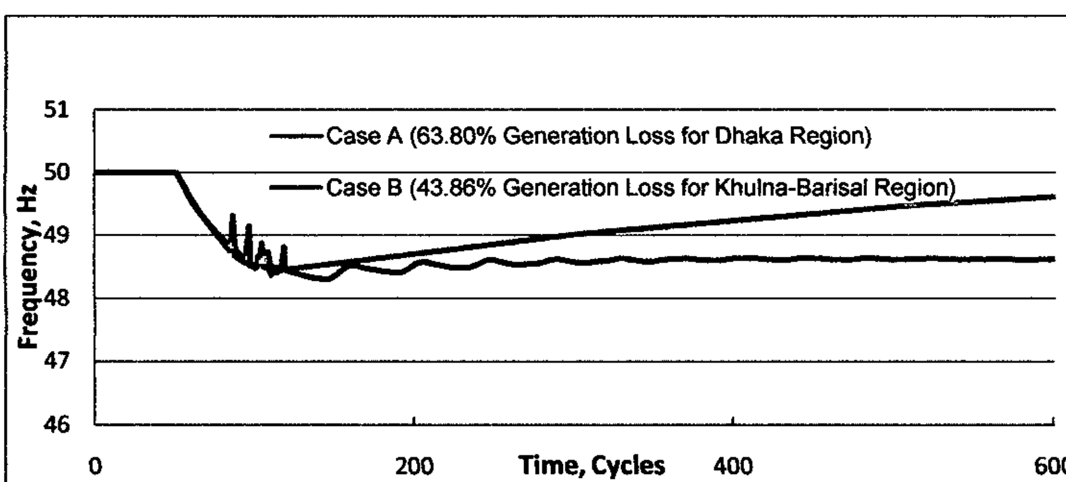

Fig. 5.26 Comparison of generation outage when both FS & FD relay based load shedding schemes applied on different sizes of islands.

5.3.3.4 Auto load shedding using relays to compensate cascaded effect

The combination of different amount of load addition and generation outage for both Dhak and Khulna-Barisal islands are summarized in table 5.5 and table 5.5. When traditional load scheme is applied to both islands larger amount of load can be added to Dhaka Island than Khulna-Barisal Island for approximately same amount of generation loss and frequency response characteristics are shown in fig. 5.27.

Table 5.5 Percentage of load addition and generation loss for fig. 5.27

Case	Case A	Case B
Region	Khulna-Barisal	Dhaka
Load Addition	18.05%	32.72%
Generation Loss	19.73%	19.40%

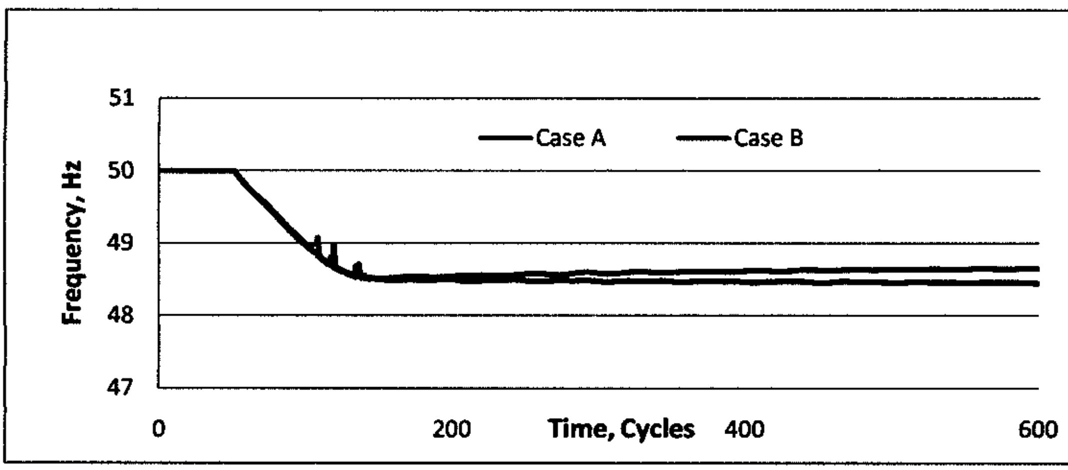

Fig. 5.27 Frequency response for different sizes of islands using only FS relay based load shedding scheme to compensate cascaded effect.

Table 5.6 Percentage of load addition and generation loss for fig. 5.28

Case	Case A	Case B
Region	Khulna-Barisal	Dhaka
Load Addition	36.09%	71.98%
Generation Loss	26.99%	26.60%

Fig. 5.28 shows frequency response for cascaded effects when both traditional and adaptive load shedding schemes are applied to both islands with same FS and FD relay settings; the Island Dhaka shows stable operation for a larger amount load addition than Island Khulna-Barisal with approximately same amount of generation outages.

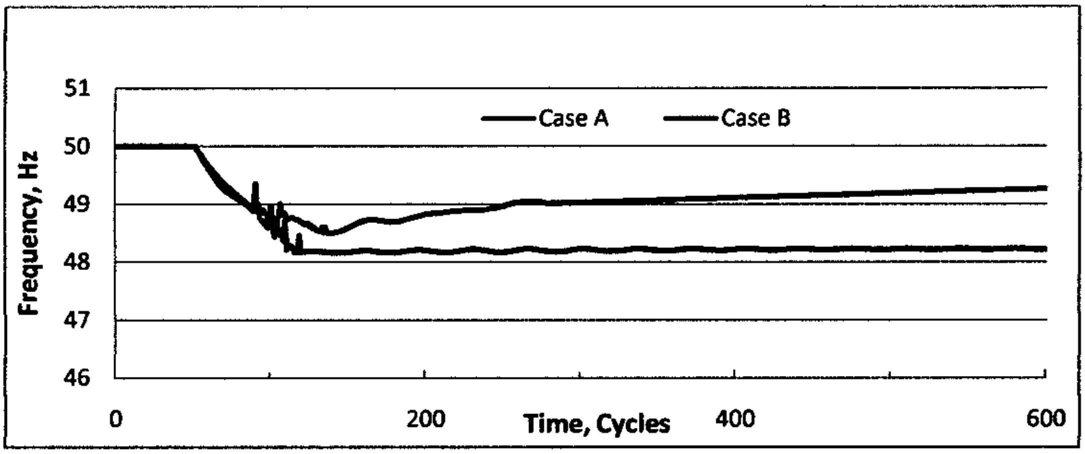

Fig. 5.28 Frequency response for different sizes of islands using both FS & FD relay based load shedding scheme to compensate cascaded effect.

5.4 Conclusion

From the discussion of previous sections of this chapter it is clear the larger islands show stable operation than smaller islands for bigger amount of sudden load addition, generation loss or combined effect of both and from the discussed on chapter 3 it is proven that larger islands have bigger overall system inertia constants. So finally based on simulation results it can be deduced that when an integrated system will be spillted into islands because of extreme abnormalities; the sizes of islands must be kept as large as possible as the larger islands show more stable operation for larger amount of disturbances.

Chapter 6
Conclusion

6.1 Concluding Remarks

Abnormal conditions or disturbances to power system create fluctuations to electrical quantities such as voltage, frequency and current. Most of the abnormal conditions to a power system lead to fall of frequency and sometimes extreme abnormality leads to blackout of an integrated system. Planned and proper islanding may protect the system from complete blackout in case of extreme abnormalities. Though traditionally interconnection standards avoid islanding operation but in case of emergency islanding are allowed to support power supplies to critical and important loads to improve service reliability.

The period immediately after an abnormal condition, the frequency deviation is primarily dependent on the magnitude of inertia of the system. The inertia constant H describes the inertial response, the bigger the value of this constant the higher the stability of the system. The simulated results of different sizes of islands clearly show that the stable operations of islands depend on the sizes (in terms of MW) of the islands. As the larger sizes of islands have higher inertia constant hence shows more stable operation than smaller sizes of islands.

6.2 Suggestions for Future Works

The rapidly growing electric power industries develop many reasons for system instability. Therefore, the assessment and the enhancement of power system stability still an active research area. The goal of this research was to investigate and to compare the impacts of sizes (in terms of MW) of islands on the stability of a faulted power system to develop the principle of formation of islands during disintegration of a faulted system. The followings are the suggestions for future research in this area:

1. The effects of high starting torque loads, such as large motor of different sizes in an island may be investigated in terms of stability.

2. The architecture of distribution network may be developed so that a successful islanding scheme may be created to help better stable system.

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Appendix

Appendix A: Load Flow Results of BPS

LOAD FLOW STUDY PARAMETERS		
Study :	UNTITLED	
Time :	Sun May 13 06h12m12s 2012	
Method :	Newton-Raphson	
Constraints :	Applied	
Flat start :	No	
Tcul txfo used as fixed tap :	No	
Block Q-flow Txfo Adjustment	n\a	
Block P-flow Txfo Adjustment :	n\a	
Block Switchable Shunt Adjustment :	n\a	
Block DC Link Adjustment :	n\a	
Base power :	100.00 [MVA]	
Tolerance :	0.100 [MVA]	
COMPLETE SUMMARY REPORT		
Summary Data	**Active Power**	**Reactive Power**
Total generation	5245.609	1847.564
Spinning reserve	1738.116	
Static Load	5133.439	2568.72
Shunt loads	0	-1636.437
Motor loads	0	0
Total load	5133.439	932.282
Line / cable losses	92.717	-29.57
Transformer losses	19.451	944.851
Total losses	112.168	915.281
Mismatches	0.002	0

SUMMARY REPORT FOR ZONE: z1		
Summary Data	**Active Power**	**Reactive Power**
Total generation	577	144.086
Spinning reserve	323.91	
Static Load	833.3	416.65
Shunt loads	0	-349.872
Motor loads	0	0
Total load	833.3	66.778
Line / cable losses	10.946	-71.293
Transformer losses	1.778	81.67
Total losses	12.724	10.377

SUMMARY REPORT FOR ZONE: z2		
Summary Data	**Active Power**	**Reactive Power**
Total generation	456	120.272
Spinning reserve	69.852	
Static Load	283.5	141.75
Shunt loads	0	-9.279
Motor loads	0	0
Total load	283.5	132.471
Line / cable losses	4.489	-5.88
Transformer losses	0.698	33.741
Total losses	5.188	27.861

SUMMARY REPORT FOR ZONE: z3		
Summary Data	**Active Power**	**Reactive Power**
Total generation	203	101.535
Spinning reserve	7	
Static Load	350.7	175.35
Shunt loads	0	-57.883
Motor loads	0	0
Total load	350.7	117.467
Line / cable losses	10.012	12.978
Transformer losses	0.585	27.302
Total losses	10.597	40.281

SUMMARY REPORT FOR ZONE: z4		
Summary Data	**Active Power**	**Reactive Power**
Total generation	3016.109	1200.941
Spinning reserve	904.963	
Static Load	2119.24	1059.62
Shunt loads	0	-499.882
Motor loads	0	0
Total load	2119.24	559.738
Line / cable losses	15.35	-75.843
Transformer losses	13.072	652.029
Total losses	28.422	576.186

SUMMARY REPORT FOR ZONE: z5		
Summary Data	**Active Power**	**Reactive Power**
Total generation	386	169.481
Spinning reserve	189.165	
Static Load	817.4	408.7
Shunt loads	0	-374.534
Motor loads	0	0
Total load	817.4	34.166
Line / cable losses	33.464	106.907
Transformer losses	2.113	92.554
Total losses	35.577	199.46

SUMMARY REPORT FOR ZONE: z6		
Summary Data	**Active Power**	**Reactive Power**
Total generation	607.5	111.249
Spinning reserve	243.226	
Static Load	729.3	366.65
Shunt loads	0	-344.988
Motor loads	0	0
Total load	729.3	21.662
Line / cable losses	18.456	3.561
Transformer losses	1.206	57.556
Total losses	19.662	61.117

Appendix B: BPS Grid Network on Map