In this chapter, literature review pertaining to the topics of studies is presented.

Electricity has become the fundamental need of a modern society. Secured reliable maintenance of supply by the power utilities is a challenging task. Keeping power system in secured state means, that the risk of disturbance to spread from small initiated faults to the other parts of the system, which may lead to endanger the system integrity, to be curtailed.

2.1 CRITICAL FAILURES

In this power systems an initiating event failure increases the stress of the other system components resulting in possible overloading above the limits for which this were disturbed the outage of overloaded components can progress either slowly or quickly [14] resulting into cascading failure. The elements in the cascading failures are primarily transmission lines, transformers and generators. The initiating event is a component trip. The transient progression usually involves the instabilities like voltage instability, frequency instability and angle instability.

When the security is jeopardized and the power system is subjected to a disturbance which is not eliminated, can lead to catastrophic failures [15] having a very serious impact on the power systems. If this happens, certain protective measures should be actuated, so that the power system could be prevented from total collapse or blackout.

The power systems worldwide experienced a number of blackouts and had a tremendous impact on the society. The investigation in the sequence of events of cascade for the large scale blackouts is seeking, to understand how and why the cascade leads to system disintegration. When the island form is not prearranged, the unbalance of generation and load is resulting into blackout [16].

2.2 DATABASE OF BLACKOUT

The major incidences of blackouts occurred with affected Population (million) and Locations are, 30th – 31st July 2012 in India blackout (670), 2009 Brazil and Paraguay blackout (87), Central, south and southeastern Brazil and all

Paraguay November 2009, Java Bali blackout (100) Indonesia, 18^{th} August Italy blackout (55), Italy 28^{th} September 2003, Northeast blackout (55), North America, northeastern US 14^{th} -15^{th} August 2003, 1999 Southern Brazil blackout (97) South and southeastern Brazil 11^{th} March 1999, Northeast blackout (30) and North America, Canada 9^{th} November 1965.

The cascade failures, initiated by overload, causes the load sharing or generation evacuation onto the other parallel lines. This additional load transfer causes further tripping of lines resulting in abnormal overloads and voltage drops, causing the failures due to voltage collapse. This uncontrolled cascade would ultimately violate the system integrity leading to blackout. Since the blackout could be catastrophic to the power system, there is an immediate need of innovative approaches in order to investigate the changes in the security planning to avert any disturbance leading to grid collapse.

There are various models used to study the impact of cascade collapse in complex systems. The cascade model of cascading failure was studied for the power system with 1000 identical components randomly loaded [17]. An initial disturbance adds additional load 'd' to each components and causes some more components to fail by exceeding their loading limit. The failure of a component causes a load increment 'p' for all the other components. As the components fail, the system becomes more loaded and cascading failure of further components becomes likely. This model is simple enough with minimum representation of cascading failure.

There are different mechanisms in cascading failures of power system, by which one failure can cause the other failure. One common feature of blackout is the successive failure of transmission lines. Another approach for modeling the blackout failures is using branching process [18]. The branching process model is an obvious choice of stochastic blackouts as this was developed and applied to the other cascading process such as, initial spread of epidemics and cosmic rays and avalanches in idealized sand piles. The first suggestion to apply branching process to cascade failure in blackouts is in the reference [19].

In branching process, modeling the way to study the cascade failure is to consider the failures propagating probabilistically according to a Galotn-Watson-

Bienayme. In this process, each failure, generates failure in subsequent stages according to distribution with mean ‘λ’, which is a measure of propagation of failures [20].

However, all the above mentioned models will help in assessing the criticality of the disturbances in the event of cascade failures. The actual system requirement for the power system utilities is to get equipped with the required controlled schemes to mitigate the large-scale disturbances and to avoid the total system blackout.

On September 28th 2003, the Italian power system experienced a major blackout affecting an estimated population of 60 million people with energy loss of 180 GW. S. Corsi et al. [21], made a study on “General Blackout in Italy”, Sunday September 2003, and confirmed that the initial event leading to Italian blackout started due to the transmission line overloading and the absence of adequate counter measures/control to avert this dangerous operating conditions.

R.M Moraes et al., [22], presented the Brazilian experience and the importance of protection requirements in minimizing the risk of cascading tripping, by adopting component protection and inclusion of the short term operation planning procedure in the grid code. Blackout analysis revealed that the outages of certain critical lines resulted into heavy transfer of power over the other lines, moved the system into an oscillating condition which was turned into unstable phenomenon right after tripping of the lines connecting to the power plant.

One way suggested for preventing the occurrence of a large disturbance is to evaluate the system condition with single or multiple faults. The results will be fed back to the operation planning studies and the power systems to be prepared to operate as safe as possible by suitable configuration of special protection schemes.

2.3 SPECIAL PROTECTION SCHEMES

P.M Anderson Et al. [23], made the presentation of the Joint IEEE-CIGRE survey to demonstrate the experience with the special protection schemes in his paper “Industrial Experience with Special Protection Schemes” and suggested the need of watchdog type scheme that could be armed at higher load levels and not at lower load levels in response to the system conditions.

Though, the research initiations were proposed in the year 1996, now it is finding its application in power industries. This is mainly due to the fact that transmission owners are facing challenges i.e. when the new generators are added to the system without transmission system strengthening, deregulation, high cost building new transmission infrastructures and time constraints have placed the transmission system owners under tremendous pressure to maximize the existing asset utilization. The primary effect on the power system that occurs as a result of non availability of SPS is the, generation instability as a major event, then followed by voltage instability, system separation and loss of load etc. The very important observations that were made from the survey reports of ‘CIGRE and IEEE’ was that the

1. Development of guide lines for SPS designing based on the requirements.
2. The degree of complexity is rapidly increasing and solutions required are more and more sophisticated.
3. All installed Special Protection Schemes are dedicated solution for the particular power systems. There is no scheme that could be applied to another power system with minimum modifications.
4. The primary effect on the power system, that occurs due to the absence SPS, is an important issue under consideration from the survey responses as shown in the Fig 2.1. The generation instability is the effect that was observed by many utilities, which indicates that many special protection schemes should focus on this aspect.

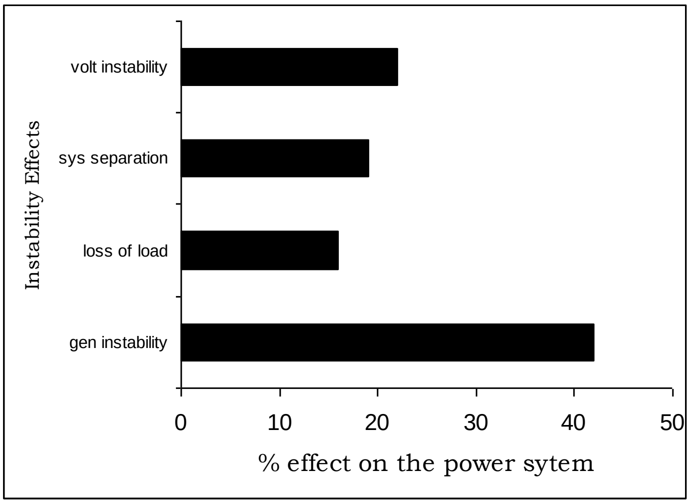

Fig. 2.1: The primary effect of the SPS absence

5. It was also inferred from the survey that the most adoptive SPS schemes among the various types given in the table 2.1 is of the type generation rejection, amounting to 21.6%. **Hence, in this thesis the most essential type of SPS is considered for designing and implementation to the state utility.**

6. The growth rate of SPS implementation is shown in the table 2.1. This indicates that there is a significant growth in the population of, the usage of SPS

Table 2.1: SPS Survey Studies

1989 Survey		1996 Survey		2009 Survey	
Respondents	Schemes	Respondents	Schemes	Respondents	Schemes
18	93	49	111	110	958

Types of SPS	Percentage
Generator Rejection	21.6
Load Rejection	10.8
Underfrequency load shedding	8.2
System Separation	6.3
Turbine Valve Control	6.3
Load & Generation Rejection	4.5
Stabilizers	4.5
HVDC Controls	3.6
Out-of-Step Relaying	2.7
Discrete Excitation Control	1.8
Dynamic Braking	1.8
Generator Runback	1.8
Var Compensation	1.8
Combination of Schemes	11.7
Others	12.6

P. Gomes et al. [2], in their study on “Brazilian experience with system protection schemes” suggested the need for development of different SPS as operative resources for maintenance of electrical system security. Under frequency control is the focus where the greatest number of SPS was concentrated. All the distribution utilities maintain their own under frequency load shedding schemes as the Brazilian electric system is equipped with long transmission lines with higher loadings which are subjected to under frequency when dealing with multiple contingency.

The Itaipu hydro power plant in south of Brazil was producing 18% of the Brazil energy requirement. The outage of single transmission system element led the system to operate close to its permissible limits, thereby increasing the possibility of major disturbances. One of the measures adopted in brazil to allow the maximum energy transfer among the areas, is the utilization of SPS for providing the adequate load shedding in the required area ensuring the frequency control in the event of loss of interconnection between the regions, thus avoiding the total system collapse with the experience of Brazilian electric power systems, due focus was made for implementation of greater number of SPS for the under frequency control, for the utilities in providing the under frequency load shedding scheme.

With growing complexity of power grids in the world, it has been found that the utilization of SPS is one of the means most commonly utilized to guarantee the performance of power system. Utilization of SPS in Brazilian electric system helped to keep the operative security in the event of occurrence of great disturbances and during the critical hydrological periods.

T.Y Hsiao, et al. [24], suggested the requirement of SPS can be identified performing the offline studies, to estimate the system responses to the studied events and contingencies, and then the design criteria for SPS to be adapted to fulfill the necessary action to control the cascade events. Miroslave Begvic presented the key issues and design considerations for the new generations of SPS, emergency control schemes and their strategic evaluation. [25].

A special protection scheme to address a local low voltage problem and zone-3 protection in KEPCO (Koria electric power corporation) system was presented by Ki-Seob Yun, et al. [26]. SPS was established in KEPCO system, after experiencing low voltage profile in part of the system in the event of DC tower outage. Without SPS the outage was triggering the operation of zone-3 relay and trips the total system due to over loading. SPS was implemented for under voltage load shedding to curtail over load.

The report prepared by the Task Force on understanding, the prediction, mitigation and restoration of cascading failures of the IEEE computing and analytical methods (CAMS) subcommittee presented in the paper “Mitigation and

Prevention of Cascading Outage: Methodologies and Practical Applications” [15], the practical examples of SPS applications in the WECC and Italian Systems etc., and the need for properly designed and coordinated SPS for mitigation and prevention of the cascade outages.

Based on the literature survey and the system utility need the focus is made on the design of SPS in this thesis, with newly developed **algorithm for determining the arming limits and actuation of SPS**.

2.4 ISLAND SCHEMES

The power system worldwide have experienced number of blackouts what so ever may be the reason like growth of sudden loads in urban, forcing the utilities to operate close to the maximum capability of transmission system, protective relays operated by overloads at depressed system voltage, increasing the possibility of unstable swings among the generators whenever the severe faults occur in the system. The ultimate cause of cascade blackout is the uncontrolled power system configuration changes and partition, Meng, et al. [16], referred to the 14th August 2003 US/Canada Blackout wherein the controlled islanding had not been prearranged and the study demands the need of islanding as backup when the system integrity is difficult to be maintained. Usually, the islanding in the power system occurs due to the severe disturbances causing the system disintegration. The uncontrolled islands could not survive due to the generation load mismatch. Hence, the predetermined island schemes were needed to be implemented as a protective control measure.

A controlled islanding development methodology was proposed by a handful of research scholars as an appropriate corrective control measures against the large disturbances. Some schemes have been described in the literature with IEEE bus data, and some other are in the planning phase for implementation. Control islanding scheme split the system into smaller islands. Many studies depict that the islands formed due to the major disturbances are unintentional and the island occur in unplanned fashion and hence the survival is doubtful [27]. To overcome this issue, the intentional island scheme came into existence. An approach presented by Haibo You et al. [28, 29], suggested a slow coherency based islanding by cohesive grouping of generators and demarcation of minimum cutsets in order to form the island. The method assumes that the state variable of nth order system are divided into ‘r’ slow states Y, and (n-r) fast states Z, in which the ‘r’ slowest states represents ‘r’ groups with slow coherency. This includes the development procedure for grouping of generator and identifying the weakest link to form the islands. This was simulated with 179 bus test system.

Li et al. [30], proposed a controlled islanding approach based on the graph spectral method for identifying the groups strongly connected sub networks based on the development of k partitions with the eigen vectors of the graph ‘G’. The power network is divided into k disjoint areas simultaneously with the consideration of the least generation load imbalance. This was simulated with 179 test bus system.

Sun et al. [31], described the real-time controlled island scheme based on the OBDD (Ordinary Binary Decision Diagram) and studied for 118 bus system.

A. Gjukaj et al. [32], discussed the aspects of the redesign of Load Shedding schemes with respect to actual development in the Kosovo Power Systems. The load Shedding is a type of emergency control that was designed to ensure the stability by reducing the power system load to match the generation supply. A new adaptive load shedding technique was provided as emergency protection against the frequency decline in cases when the Kosovo power system might be disconnected from the regional transmission network forming the island.

Sangsoo Seo et al. [33], outlined a frame work for determining the necessary reactive power compensation instead of load shedding to restore the power systems. For adequate compensation strategies, weak buses are used as compensation locations for addressing the voltage stability, especially, in the events of severe contingencies. However, these methods suffer from the drawback of immediate development of models for the utility needs with the existing system operating condition and data capture facilities. Most of the approaches require a great deal of computational effort, involving complex algorithm with the application specific IT tools like DYNRED, Dynamic Reduction Program. It was found that in the system operation, following the large disturbance group of generators swing together and hence the attention was drawn on the stability of the inter-area oscillations between the number of small groups of the machines. All these methods used for capturing the movement of generators between the groups under disturbance and hence viewed as how to form the slow coherency generator grouping and forming the island. None of the methods considered the choice of specific loads in the design of island scheme.

Now in this new regime, with the increasing penetration of the major generating power plants as the power sources and with demand side participation, an effective new approach is found required to be an immediate solution for the formation of island accessible to the state utilities. In the formation of islands, where the research approaches are yet to focus, on the load grouping concept. The island formation is considered as last resort of protection in the event of total blackout, hence, in this thesis, **a new island scheme is proposed and implemented,** considering the load grouping to feed the essential loads with the existing operating conditions, available IT tools and SCADA system.