OPTIMAL BATTERY SIZING FOR CONTINGENCY ALLEVIATION IN POWER SYSTEMS

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Submitted by

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DECLARATION

This is to certify that the thesis entitled, "Optimal Battery Sizing For Contingency Alleviation In Power Systems" submitted by Nilima Sadashiv Kakde (Roll No. 802042018) in partial fulfilment of the requirements for the award of Master of Engineering Degree in Electrical Engineering with specialization in Power System during 2020 -2022 at the Thapar Institute of Engineering and Technology, Patiala is an authentic work carried out by me under the supervision and guidance of Dr. S. K. Aggarwal.

The matter presented in the thesis has not been submitted to any other University / Institute for the award of any Degree.

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It is certified that the above statement made by the student is correct to the best of my knowledge & belief.

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ABSTRACT

Maintaining system security is a very challenging task for power system operators, because it provides information about the system state in the event of a contingency. Contingency analysis techniques are required to maintain the security and dependability of the power system. It is usually used to estimate the consequences of outages caused by events such as equipment failures, transmission line breakdowns (failure), etc. Because of the large number of components in a power system, conducting an offline analysis to estimate each individual contingency's effect is a difficult procedure. In reality, even a less number of situations will result in serious power system conditions. A method for characterising these severe conditions is called contingency selection, and it involves calculating performance indices for each contingency. Numbers of strategies are used to perform the contingency analysis. During this study the various strategies of contingency analysis are discussed. In this work, the use of linear sensitivity factors for determining installation post-contingency flow in real time is presented. The potential use of battery storage to boost transmission capacity in thermally limited transmission lines is described in detail. A transmission system's use of batteries can improve the transmission capacity of sensitive zones and reduce thermal load. In order to reduce the thermal load on the transmission line caused by the contingencies, the batteries are used. The Analytical Hierarchy Process (AHP) method is presented for calculating the capacity of a battery providing support during N- 1 contingencies and also this process is used to provide the relative importance of the various contingency parameters when calculating their respective significance in calculating battery capacity. The proposed process has been tested on the IEEE 30 bus system.

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INTRODUCTION

1.1 OVERVIEW

Power System (PS) Security is the capability of the system to overcome in some disruptive situations (contingencies) without affecting customer protection, reliability and installation. In addition, it is mentioned as the energy or the robustness of several systems to impending disturbances and it depends on the operating environments of the system and unknown potential situations. If the system is defective from a safety point of view, it is susceptible to failure. Therefore PS has the maximum consequence in a protected, dependable, constant and economic working condition.

PS security is the possibility of system's working situations which must continue in the sustainable ranges. From an operational and planning perspective, this function is quite important. There are numerous factors that contribute to the strength, dependability, and safety along a lengthy road. Primarily, the main concern in PS should be properly designed with safety. The next most important concern is continuous monitoring throughout process and maintaining suitable ranges. The third concern, good engineering is needed to accomplish these performance target, which mostly depend on the use of the devices used in this analysis. The environmental variations occur for the analysis of the safety demand of power supply and their calculations and in the same way changes the PS analysis device.

In PS, the transformers, transmission lines and generators are the study of outage of components by contingency analysis and examination of the resulting effects on line flows and bus voltages. Contingency analysis is used to calculate violations caused on by a single transmission line or transformer failure that results in overloads in other branches and/or a dramatic rise or fall in voltage.

Contingency analysis is a significant device for sensing the all possible congestion situations, demanding the power network organiser computational speed and alleviate of detection. The Engineer's always selected the performance indices calculated because of the results of this contingency analysis are generally ranked during the analysis. Several techniques for analysing the power system's contingency. The primaries used in most methodologies are a flow of Alternating Current (AC) load and arithmetic estimation.

There are a number of approaches to contingency screening that have been developed. The Newton-Raphson load flow (NPLF) process is used extensively to compute the performance index is based on conventional method[7], because of the complexity and large scale of the existing electrical system. Contingencies need to further analysed and Calculations are necessarily done quickly. The most important problem with any potential outage is that it won't affect the transformer and load on the cables or the voltage drops in the network pointes. As a result, there is no need to take into reason all possible failures for computer simulation purposes. For contingency screening, it is needed to identify the outages that have the potential to affect to the maximum system overloads and voltage falls. These crucial and probable contingencies need to be rapidly identified for a more thorough selection process and to rank the outages according to how much they will affect the current system, or contingency ranking must be planned. Approaches for contingency selecting backup plans are based on the Performance Index (PI), which can indicate a bus voltage drop limit or line overloading violation and after then, it is categorized to arrange the contingencies by severity. Using ranking algorithms or screening techniques, this step involves selecting the possible contingency cases, and it has been the subject of much research in recent years. The indirect computation of the MW violation categorization utilised many mathematical techniques, including the most recent distribution method, limiting method, expert method as well as contingency selection approaches.

Energy storage has demonstrated its ability to sustaining and improving the performance of the electrical system and providing important benefits in a number of ways. This technology (Energy Storage) allows power supply and maintenance system operators to store energy after usage. An electrochemical device considered as a battery energy storage system (BESS) that collects (charge) energy from the grid and also discharges that energy later to deliver electricity or additional network services if required or demanded. A number of technological choices, including battery storage, can increase the flexibility of the power system and enable significant levels of renewable energy integration and to make the system work better dependability and avoid system upgrades. Its application in a transmission system, mainly the discharge of thermal load, and this is the main topic of this chapter.

1.2 LITERATURE SURVEY

The power performance index is used to evaluate the power system contingency [1]. In order to calculate the network sensitivity factors, direct current (DC) load flow equations were used. Additionally, a contingency analysis was used to demonstrate the effects of both line and generator outages on a power system network. In [2], the application of linear sensitivity factors technique in the form of PTDF & LODF is used. The comparison of the AC and DC power flow analysis has been done & found out that the percentage flow rate of each technique is approximately the same. Ejebe and Wollenberg were the first to propose a selection criteria based on the calculation of performance indices using contingency, where the performance index can be used to rank the contingencies values that best reflect their severity [3]. The contingency selection for a single transmission line outage is provided in [4] by active (PIP) and reactive (PIV) power performance index are two different performance indices that are calculated using FDLF. The presented strategies for contingency analysis make use of sensitivity factors and AC power flow. The method used to select contingencies selection is important since it allows for the elimination of a large number of potential contingencies and concentrates on the more serious cases, one because the list of potential contingency cases for a complex network is very long. AC power flow algorithms have been applied and discussed in outage cases in [5].

Using distribution factors, [6] and [7] showed how the effects of the line flowing by line and generator outages. The concentric relaxation approach was introduced by the authors in [8] for contingency evaluation. The zero mismatch method is presented in [9] for instant power flow solutions. The selection of performance indices' weighting coefficients for contingency ranking has been described in [10]. In [11] presented to apply an iterative method to determine eigen values for contingency ranking under an outage circumstance. The authors of [12] obtained post outage Using a decoupled load flow and mitigation technique, voltages are ranked according to performance. The significance of power system security calculation for prediction of bus voltages and line flows following a contingency has been discussed in [1-2]. The problems that must be overcome for security analysis algorithms to be used in application were also discussed in the paper. Distribution factors [3–4] are used to determine the approximate variations in line flow caused by a generator or transmission line failure. In [5], the topic of using AC power flow solutions in outage studies was covered.

Numerous studies have been done on how to choose the correct size of the battery, the goal of minimizing power generation fluctuations, for instance, in wind farm applications [27], [28] and [29]. However, a number of articles have examined the use of batteries for thermal overload relief without going into great detail about how to determine the battery's capacity, including how to allocate charging (loading) and discharging (unloading) capabilities to reduce heat overload due to contingencies [23] and [25]. In [25], unable to determine their charging and discharging capacities, under any possible circumstance, it is assumed that a collection of batteries has been charged or discharged to their entire pre-defined capacity. For the worst condition, the battery size is easily determined in [23]. Calculations can be done with the help of the analytical hierarchy approach (AHP), the elements that weigh numerous criteria, such as probability, severity, and potential consequences, which might must an impact on sizing of the battery [30]. AHP supports in quantifying the qualitative interaction across various elements for they may be weighed in reference to a specific objective and set of criteria, compared numerically, and other comparisons. Power system problems have been solved using AHP in [31] and [32]. In [31], several objective functions were weighed using AHP, and the combined weighted objective function that resulted was applied to determine the combining active and reactive regulation with the basic objective function. There are different benefit-to-cost fractions and additional important parameters, which utilise for AHP for weighted in accordance with their respective significance in Var position, were taken into consideration for choosing and ranking the locations of Var sources in [32].

1.3 MOTIVATION OF THIS WORK

When an operating point of a power system maintained within the required ranges, then power system is protected condition, everything that provides the probability of changes in the power system. The important of safety calculation requires a PS that is necessarily reliable, protected, secure, and even in the presence of trusted contingencies. The analysis of contingencies is one of the essential and fundamental tasks of effective engineers to calculate these line outages or generator breakdowns and to take the most economic protective action possible so that maintaining the supply of the system is reliable and continuity.

1.5 PROBLEM STATEMENT

The electric power system is a complex system, whose operating condition may not remain at a constant value. The various contingencies like, large load variations, outage of components (transmission lines, transformers, generators, etc.) are more common. Any of these conditions causes overloads and system parameters to exceed the limits thus resulting in an insecure system. CA is important to alleviate the line flows in AC power system using battery storage.

This study considers the application of power flow technique and energy storage devices to dispatch the transmission lines to relieve the overload in a power system**.**

1.4 OBJECTIVES OF THIS THESIS

- To assess the behaviour of the power system status under each transmission line outage, and reveal its severity on the power flow of the remaining network branches and voltage profile on buses.
- To calculate the performance indices for transmission line and generator outages using the Newton-Raphson method.
- To identify the highest and lowest loaded lines and bus voltages.
- To determine the sizing of battery storage to alleviate thermal overload caused by an N-1 contingency.

1.5 THESIS SUMMARY

Five chapters make the work completed for this thesis,

The overview of the power system, a review of relevant literature, the objectives of the present work, and the structure of the thesis are all covered in Chapter 1.

Contingency analysis of the power system, as well as its selection, evaluation and introduction of the Newton - Raphson load flow method are covered in Chapter 2.

Use of the NRLF method and the different results for the IEEE 30 bus systems, contingency ranking is carried out in Chapter 3 by computing the performance indices (PI) of active and reactive power.

AHP method-based battery storage sizing is investigated in Chapter 4 of the work, considering the different explanations of the possible N-1 contingencies, to reduce the thermal overload affected by the N-1 contingency.

Chapter 5 gives details on the conclusions and the scope of further research.

CHAPTER-2

CONTINGENCY ANALYSIS

2.1 INTRODUCTION

The parameters of the power system can be affected by faults in any of the various electrical components and result in a power outage and exceed the system working limitations. It might result in preventing the reliable and secure operation of the power systems. When power flows and bus voltages are within working and acceptable ranges despite variations in the load or the amount of available generation, it is regarded as typical that the power system's equipment will sustain damage. The power system must be operationally secure, that is, there must be a low probability of blackout.

The concept of contingency was presented by Ejebe and Wollenberg (3). The abnormal cases in the power system tasks are introduced as a contingency. Power network contingency compromises the dependability, security, and continuity of the entire power system. The temporary interruption of power is referred to as an outage. A contingency is an attainable situation or a breakdown (outage) that is possible but is not accurately predicted. Most of the time, a transformer, generator, or line is out, and all of its components are closely checked for any possible risks. According to the definition, security is the ability that a power system's operational goal will remain throughout a steady state of process. Because of the increasing and urgent need for electrical energy, power engineers now have a much more difficult and complicated work to fulfil. They must choose a method for delivering reliable, secure, and effective power to the without interfering with a consumer.

The safe running of the electrical energy network depends on important tasks including contingency analyses. Contingencies are dangerous disturbances that could possibly happen while a power system is operating in steady state. Repeated load flow solutions are used to do contingency analysis for each potential component failure on a list. Whenever there is a significant change in the system's structure or load, this process must be repeated and carried out for all possible contingencies. After a transmission line contingency, estimating these bus and power flow voltages is essential. since both the active and the reactive power limit, which specifically affects the bus voltage, are changed. The primary topic of discussion in this chapter is the various approaches to modelling contingency analysis. There has been discussion of the contingency analysis using sensitivity factors. Additionally, a detailed presentation of the contingency analysis has been used with AC power flow. The major aim of implementing the method for using NRLF is to perform the contingency selection for contingency analysis (CA) for line and generator contingencies for 30 bus system.

2.2 BASICS OF CONTINGENCY ANALYSIS

One of the almost frequently discussed topics in security assessments of other power system is contingency planning for it is obvious that the majority of current power systems cannot handle the rise in demand given the lack of enormous development of power stations and the already complex infrastructure. For the purpose of avoiding more related cascade accidents and executing a contingency study for potentially serious events that could happen in the power grid. The simulation of individual contingencies is part of the contingency analysis for the power system model under consideration. A contingency analysis (CA) consists of three fundamental steps to make it simpler. These are listed follows:

1) Contingency creation: This stage serves as the starting point for the analysis. It includes every possible contingency that might arise in a power system. Contingency lists are created as part of this process.

2) Contingency selection: This stage, which is the second one, includes selecting the severe contingencies from the list that might lead to bus voltage and power limit breaches. In this procedure, the contingency list is reduced by removing the least severe possibilities and taking into account of most severe ones. Calculating the index for this process shows the severity of contingencies.

3) Contingency evaluation: This is the third and most crucial step because it has the necessary security and control action measures that are required to reduce the effects of the most serious contingencies on a power system. The performance index (PI) method is applied to rank those contingencies according to severity and measure the severity of each.

2.2.1 MAJOR DIFFICULTIES INVOLVED IN CA

This analysis is complicated by three main issues. The first significant issue is the challenge of changing the optimal energy system model. Second, decide which emergency situation is best to consider about. Calculating the power flow and bus voltages, which takes a lot of time in the energy management system, is the third biggest challenge in the power system.

2.2.2 RANGE OF POWER SYSTEM PROBLEMS

- **None:** When the power system can be re-balanced after a contingency, without overloads to any elements.
- **Severe:** When several components such as transmission lines and transformers become overloaded and have possibility of damage.
- **Critical:** When the power system converts unbalanced and will quickly failure.

2.2.3 NECESSITY OF CONTINGENCY ANALYSIS

Contingency analysis is a most convenient and widely used method in power system. Contingency analysis is solved difficult problems occurs in transmission line or electrical components of power flow system. Therefore, contingency analysis method is necessary power system. The necessary of contingency analysis of power system because**:**

- Contingency analysis is helps to boost system reliability
- Contingency analysis is improved for secured operation
- Contingency analysis is helps future planning and expansion of power system

2.3 SOLUTION FOR POWER FLOW

As mention above, the planning of a present PS as well as its future expansion depends greatly on power flow studies for managing the components. The calculation of voltage magnitude and phase angle, as well as calculating active and reactive power flow for every line and bus using contingency analysis method and it is a very challenging thing. Whereas power flow determining the problem and conjecture is adopted as and it is functioning in stable condition and single phase model. In this solution, each bus is connected in four quantities and these are real power (P), reactive power (Q) voltage magnitude |V|, phase angle (δ). There are three types of system buses: as shown in below

SLACK BUS: Slack bus is also known as swing or reference bus and When the voltage magnitude and phase angle are given, the slack bus also referred to as the swing or reference bus. Network losses in the power system are what cause scheduled load adjustments and variations in generated power, according to the slack bus.

LOAD BUS: Load buses are also known as P-Q bus. While the bus voltage magnitude and voltage phase angle are unidentified, and the bus active and reactive power is specified.

REGULATED BUS: Regulated buses are also recognised as P-V bus, voltage-controlled bus and generator bus. At these types, the P (active power) and |V| (voltage magnitude) are supplied, and it is necessary to determine the voltage phase angle and the Q (reactive powers).

When the power flow problem is expressed mathematically in a power system, it results in nonlinear algebraic calculations that can only be solved iteratively. In the power flow solution, there are numerous iterative strategies.

2.4 THE NEWTON RAPHSON LOAD FLOW METHOD (NRLF)

In power system, NRLF method is one of the best and widely preferred or used as compared to other methods for load flow solutions as per a result of its several benefits. It takes effective conjunction characteristics associated to another different processes and it has low calculation. The distributed system calculation is used for solving by the Sparsity–programmed (S-P) systematic removal with minimum time. The size of the problem will expand approximately linearly, and the method is highly useful for huge systems because computer storage requirements are measured. The NRLF method in starting condition is extremely sensitive to sensible and it is used reduces the time for computation extraordinarily and fast convergence. The reference bus and system adjustments requires relatively less computational effort and no demand for iteration is unaffected by the process of calculating acceleration factors. The NRLF solution methodology needs some support to simple and connection of presentation and also system has good flexibility, such as on functional loads, area interchanges, and remote voltage control as well as on-load branch altering and phase-shifting devices. The NRLF method calculates the several recently approaches developed to improve the PS process, such as sensitivity analysis in PS, calculations of system state, transient stability and security of the power system, demonstration of linear system, it be situated well related for online computation. For systems with large path angles and control devices that affect both reactive and actual power, NRLF construction is also required.

Now the current incoming the bus I of the power system is shown below:

For the bus admittance matrix Y, the polar form of the power flow equations is derived, which is provided as:

$$I_i = \sum_{i=1}^{n} Y_{ij} V_j \tag{2.1}$$

The polar form expressing as:

$$I_i = \sum_{j=1}^{n} |V_{ij}|\,|V_j| \angle \theta_{ij} + \delta_j \tag{2.2}$$

Active and reactive power are used to define the current on the bus I:

$$I_i = \frac{P_i - jQ_i}{V_i^*} \tag{2.3}$$

Substituting equation no.(2.3) in equation no. (2.2), we get:

$$P_i - jQ_i = |V_i| \angle -\delta_i \sum_{j=1}^{n} |V_{ii}||V_j| \angle \delta_{ij} + \delta_j \tag{2.4}$$

The real part and imaginary parts of power as shown:

$$P_i = \sum_{j=1}^{n} |V_{ij}||V_j||V_i| \cos(\theta_{ij} - \delta_i + \delta_j) \tag{2.5}$$

$$Q_i = \sum_{j=1}^{n} |V_{ij}||V_j||V_i| \sin(\theta_{ij} - \delta_i + \delta_j) \tag{2.6}$$

We obtained the following by using Taylor's series equations (2.5) and (2.6) around the first, evaluate and then remove the term higher order, we get:

$$\begin{bmatrix} \Delta P_2^{(k)} \\ \vdots \\ \Delta P_n^{(k)} \\ \hline \Delta Q_2^{(k)} \\ \vdots \\ \Delta Q_n^{(k)} \end{bmatrix} = \left[\begin{array}{c|c} \begin{pmatrix} \frac{\partial P_2^{(k)}}{\partial \delta_2^{(k)}} & \cdots & \frac{\partial P_2^{(k)}}{\partial \delta_n^{(k)}} \\ \vdots & \ddots & \vdots \\ \frac{\partial P_n^{(k)}}{\partial \delta_2^{(k)}} & \cdots & \frac{\partial P_n^{(k)}}{\partial \delta_n^{(k)}} \end{pmatrix} & \begin{pmatrix} \frac{\partial P_2^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial P_2^{(k)}}{\partial |V_n|} \\ \vdots & \ddots & \vdots \\ \frac{\partial P_n^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial P_n^{(k)}}{\partial |V_n|} \end{pmatrix} \\ \hline \begin{pmatrix} \frac{\partial Q_2^{(k)}}{\partial \delta_2^{(k)}} & \cdots & \frac{\partial Q_n^{(k)}}{\partial \delta_2^{(k)}} \\ \vdots & \ddots & \vdots \\ \frac{\partial Q_n^{(k)}}{\partial \delta_2^{(k)}} & \cdots & \frac{\partial Q_n^{(k)}}{\partial \delta_n^{(k)}} \end{pmatrix} & \begin{pmatrix} \frac{\partial Q_2^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial Q_2^{(k)}}{\partial |V_n|} \\ \vdots & \ddots & \vdots \\ \frac{\partial Q_n^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial Q_n^{(k)}}{\partial |V_n|} \end{pmatrix} \end{array}\right] \begin{bmatrix} \Delta \delta_2^{(k)} \\ \vdots \\ \Delta \delta_n^{(k)} \\ \hline \Delta |V_2^{(k)}| \\ \vdots \\ \Delta |V_n^{(k)}| \end{bmatrix} \tag{2.7}$$

The linearized relationship is provided by Jacobian matrix between minor variations in $\Delta\delta_i^{(k)}$ and voltage magnitude $\Delta|V_i^k|$ with minor variations in real power and reactive power ΔP_i^k and ΔQ_i^k

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} \tag{2.8}$$

The elements of J_1 are shown in diagonal and off diagonal forms:

$$\frac{\partial P_i}{\partial \delta_i} = \sum_{j=1} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \qquad (2.9)$$

$$\frac{\partial P_i}{\partial \delta_i} = -|V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j); \qquad j \neq i \qquad (2.10)$$

Similarly, we can identify the elements of J_2 , J_3 and J_4 in diagonal and off diagonal forms. The relations ΔP_i^k and ΔQ_i^k are the power residuals or the difference between the calculated values and scheduled, and it shown below:

$$P_i^k = P_i^{sch} - P_i^{(k)} \qquad (2.11)$$

$$Q_i^k = Q_i^{sch} - Q_i^{(k)} \qquad (2.12)$$

$\delta_i^{(k)}$ and $\left|V_i^{(k)}\right|$ are determinate procedure the equation no. (2.7) to complete actual iteration and calculate the new values and it is used for next iteration as shown below using the calculations of Jacobian matrix and residuals power.

The next evaluations for bus voltage are

$$\delta_i^{(k+1)} = \delta_i^{(k)} + \Delta\delta_i^{(k)} \qquad (2.11)$$

$$\left|V_i^{(k+1)}\right| = \left|V_i^{(k)}\right| + \Delta\left|V_i^{(k)}\right| \qquad (2.14)$$

CHAPTER-3

CONTINGENCY ANALYSIS USING MATPOWER

3.1 INTRODUCTION

In this chapter, Contingency ranking (CR) has been calculated by Newton Raphson power flow method. The IEEE 30 bus test case system is perform by the this conventional process. The active (PIP) and voltage (PIV) power performance indices were calculated using the results obtained using this conventional process. These two performance indices are added together to get the total performance index, completes CR once the performance indices have been obtained. Performance Index (PI) is ranked first with the ascending order and descending order of both the active (PIP) and voltage (PIV) performance index calculating the severity of the contingency.

3.2 NRLF METHOD ALGORITHM

The process for NRLF method is defined as follows:

1. In P-Q buses or load buses, the parameter Pi and Qi are given, the magnitudes of voltage value are set equivalent to the reference bus value is 1pu and similarly phase angles values is 0(degree). i.e, $|Vi|$ =1.0 and δi =0.0 for buses with voltage- regulated, where $|Vi|$ and P_i^{sch} are given, phase angles are fixed to be equal to the reference bus angle, or 0,i.e., δi =0.

2. For load bus (P-Q) $P_i^{(k)}$, $Q_i^{(k)}$, ΔP_i^k & ΔQ_i^k are calculated from the equations.

3. $P_i^{(k)}$ & ΔP_i^k are evaluated by voltage controlled buses from the corresponding equations.

4. The fundamentals of Jacobian matrix (JM) (J_1, J_2, J_3, J_4) are estimated.

5. The Gaussian elimination and optimally triangular factorization has been performed directly in linear simultaneous equation.

6. The phase angle and new voltage are calculated.

7. The procedure is repeated perform in expectation the residuals ΔP_i^k & ΔQ_i^k are less as compare to the specified accuracy.

3.3 SENSITIVITY FACTORS PERFORM IN CONTINGENCY ANALYSIS

If a quick display of the data is desired, it becomes quite difficult to address the problem of analysing thousands of potential outages. Applying sensitivity factors (SF) is one of the simplest and most straight forward techniques to offer a quick calculation of potential overloads [1]. These sensitivity factors, which are derived from the DC load flow, show how the system conformation has changed in comparison to the change in power flows caused by changes in a generation.

3.3.1 CATEGORIES OF SENSITIVITY FACTOR

(1) Generation shift distribution factors (GSDF)

The GSDF are selected *ali* and as shown below definition:

$$a_{li}=\frac{\triangle f_l}{\triangle p_i} \tag{3.1}$$

Where,

l = List of line

i= List of bus

$\triangle f_l$ = change the power flow in MW on line l

$\triangle p_i$ = generation shift at ith bus

It is considered that the modification in generation $\triangle p_i$ is accurately compensated by a fluctuation on the opposite at the reference or slack bus in generation, and that every extra generator is stable. The sensitivity factor (SF) of the line flow *l* resulting from change at the bus *i* in a generation is thus described by the *li* factor.

If the generator was producing P_i^o MW and it was absent, it is denoted by $\triangle \boldsymbol{p_i}$, as the recent generating

$$\Delta P_i = -P_i^o \tag{3.2}$$

A pre calculated set of "a" factors are calculated by the power flow on every line in the system as follows:

$$f_l = f_l^o + a_{li}\Delta P_I \qquad \text{for } l = 1 \dots\dots L \tag{3.3}$$

Where,

f_l line flow l with the failure of the generator on bus i

f_l^o = previous to the failure

Every line outage flow f_l can be compared to its limit, and any outages that are more severe than that are considered alarming. This would alert the operations, in particular, to the possibility of an overload on line l in the event that the bus i generator failed. The change in flow with a bus of power is calculated by the generation shift sensitivity factors (GSDF). Hence, superposition can be used to calculate the consequences of sudden changes on some generating buses.

(2) Line outage distribution factors (LODF)

The line outage distribution factors (LODF) are operated in a parallel way, when transmission system are lost then Only the tests for overloads are affected by them or maximum power flow on the line. By explanation, the line outage distribution factor (LODF) as shown below:

$$d_{l,k} = \frac{\Delta f_l}{f_k^o} \quad (3.4)$$

Where,

$d_{l,k}$ = distribution factor of line outage when line k is an outage then observing line l

Δf_l = change on line l in megawatt flow

f_k^o = main flow on line k before it was outage after i.e. opened

If one identifies the power on line l and k, the line flow l with line k out can be calculated by "d" factors.

$$f_l = f_l^o + d_{l,k}\, f_k^o \quad (3.5)$$

Where,

f_l^o and f_k^o = pre outage line flows l and k, respectively

f_l= line flow l with line k out

By pre computing LODF, a simple and rapid technique may be arranged to check each line in the system overload regarding a certain line's unavailability. Moreover, the LODF system in every line can be reiterated for the outage due to overloads in the process of sending alarm alerts to the action personnel. In order to run a CA research of power system, the GSDF and LODF methodologies can be utilised to build a digital computer. It must always check the line flow, whether positive or negative, fl max and fl max. It is assumed that the generator results for every generator in the power device are supplied, together with each transmission line, line flow inside the system, and the sensitivity factors (SF), which have been computed and saved.

3.4 PERFORMANCE INDEX IN POWER SYSTEM

In power system, many terms are presented like active power (MW), reactive power (MVAr) and bus voltage magnitudes by using the benefit of contingency analysis using AC power flow. Using the AC PF voltage limit and overloads violations. In this work, the CR outages of every line flows has been measured. The performance indices rank the severity of a certain situation. The indices are computed in an offline way using conventional power flow techniques. The results of the conventional technique are then sorted in descending order, with the greatest PI value being listed first. For contingency analysis, two kinds of performance indices [9] are frequently used. They are:

(1) PIV (Voltage performance index)

(2) PIP (Active power performance index)

(1) PIV (Voltage Performance Index):

The PIV describes the lack of a power system due to bus voltage violations [2].

$$PI_v = \sum_{i=1}^{n} \left(\frac{W}{2z}\right) \left\{\frac{|V_i| - |V_i^{sp}|}{\Delta V_i^{lim}}\right\}^{2z} \quad (3.6)$$

Where,

$|V_i|$ denotes the voltage magnitude at ith bus.

$|V_i^{sp}|$ denotes the identified voltage magnitude at ith bus.

$\Delta V_i^{lim}$is the voltage deviation limit which we can measure by taking average value of min and max permissible voltages at bus i.

z is the penalty function's exponent, and value is equal to 1. i.e. (=1).

n is the number of buses, in the specified power system

W is the actual non negative weighting factor and value is equal to 1. i.e.(=1)

Here to calculate ΔV_i^{lim}, the max voltage boundary is 1.05 p.u and min voltage boundary is 0.95 p.u since ±5% voltage deviation is acceptable. The information regarding the change in voltage at each and every bus will be provided by this voltage performance index.

• The reactive power generated by the producing units influences the bus voltages, and PIV increases the severity of irregular voltages until the reactive power reaches its limits.

• In contingency analysis, reactive power might be close to its limits. In this situation, the AC load flow computes the bus voltages while taking the reactive power constraints into consideration, and as a result, a voltage violation is evident from their actual voltage at the generator buses.

• In this situation, the generators' reactive power constraints are a part of the voltage analysis during contingency.

$$PI_{VQ} = \sum_{2n}^{N_B} \left(\frac{W}{2n}\right) \left\{\frac{|V_i| - |V_i^{sp}|}{\Delta V_i^{lim}}\right\}^{2z} + \sum_{i=1}^{N_G} \left(\frac{W}{2n}\right) \left\{\frac{Q_i}{Q_i^{max}}\right\}^{2z} \quad (3.7)$$

Where,

Q_i- denotes the flow of reactive power at ith bus

Q_i^{max}- denotes the flow of reactive power limit at ith bus

N_G- No. of generating units

W -Actual non-negative weighting factor=1

2. PIP (Active power performance index)

A PIP is one of the indices used to determine power excesses over transmission lines [9].

$$PI_p = \sum_{i=1}^{N_l} \left(\frac{W}{2z}\right) \left\{\frac{P_i}{P_i^{max}}\right\}^{2z} \qquad (3.8)$$

Where,

P_i - denotes the power flow (MW) through the line l.

P_i^{max} - denotes power flow through line l at its maximum capacity.

N_l - denotes the number of the transmission lines.

W - denotes the weighting factor and value is (=1)

Z - denotes exponent of penalty function and value is (=1)

$$P_l^{max} = \frac{V_i * V_j}{X} \qquad (3.9)$$

Where,

V_i - denotes the voltage at bus.

V_j - denotes the voltage at bus j.

X - denotes the reactance of the line between at bus i and j.

3.5 CONTINGENCY ANALYSIS ALGORITHM USING NEWTON RAPHSON MOTHOD

The following is the Newton-Raphson load flow solution algorithm for contingency analysis:

Step 1: Read the line and bus data for the specified system.

Step 2: Perform the load flow analysis for the base case without taking the line contingency into consideration.

Step 3: Removing a line and going on to the next stage in order to simulate a line outage or line contingency

Step 4: The load flow study for this specific outage is finished, the remaining lines active power flows are calculated and also the value Pmax is calculated.

Step 5: It is found that the system proposed has an active power limit violation, as shown by the active power performance index (PIP).

Step 6: Next, voltages for every load bus are determined for the specific line case (contingency).

Step 7: Following that, calculate the voltage performance index (PIV) to identify voltage limit violations at all load buses caused by line contingencies.

Step 8: for every line outage of the power system, adding PIP and PIV is performed the computation of the overall performance index.

Step 9: To calculate the PIP (active performance index) and PIV (voltage performance index) for all line interruptions, repeat steps 3 through 8

Step 10: After, the values based on of the generated performance indices, contingencies are classified (ranked) using the overall performance index (OPI).

Step 11: To obtain the results for the most severe contingency case in the system.

The flowchart for the power system contingency ranking based on the overall performance index is shown in Figure 1.

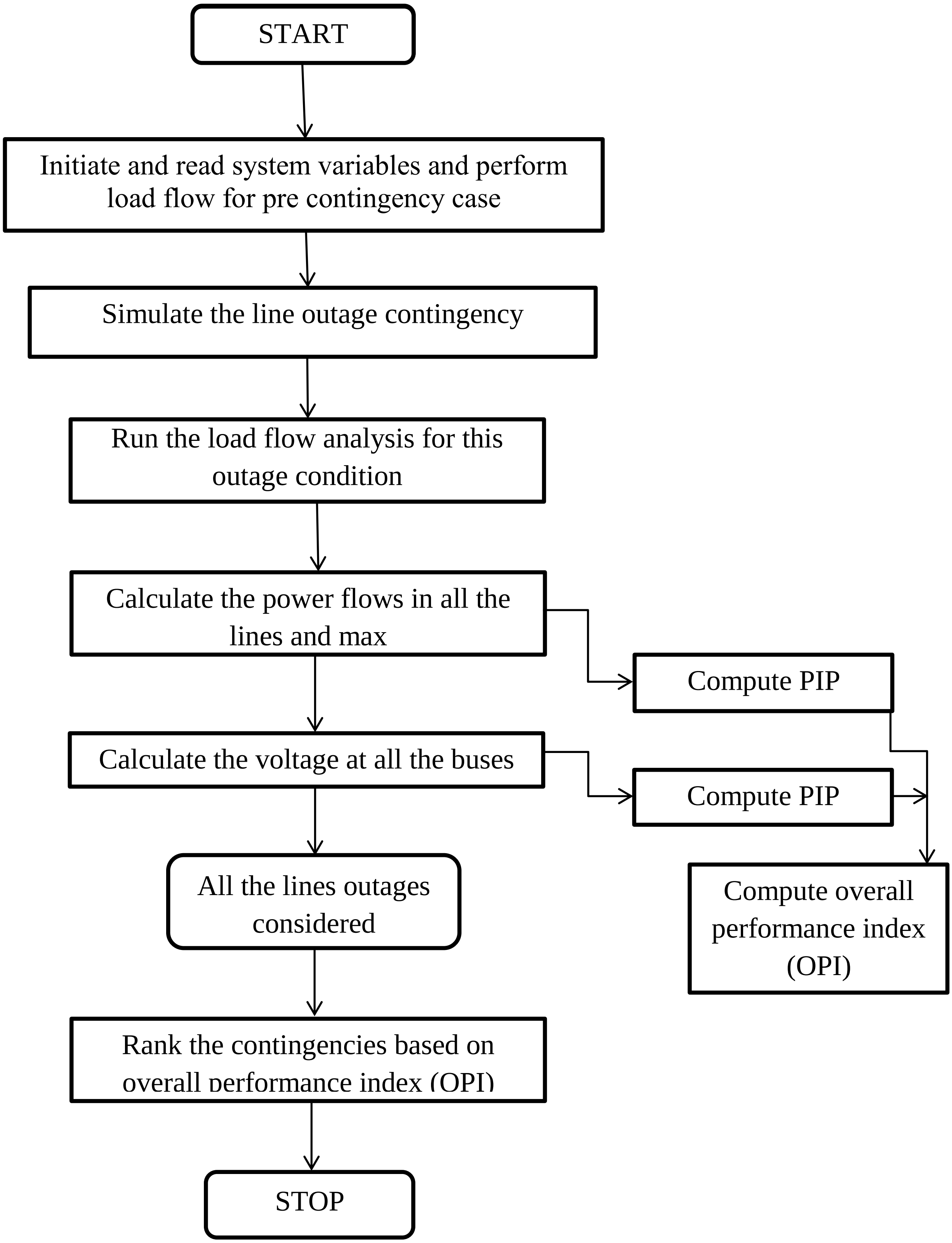

Fig. 3.1 Flowchart for contingency ranking using Newton-Raphson power flow

3.6 RESULTS AND DISCUSSION

The main aim of this work is to perform the selection process of contingency, compute the active and voltage performance indices i.e. PIP and PIV respectively. Then, the contingencies are arranged (ranked) with the most severe contingency being ranked highest (first) in terms of the performance index value. These indices were calculated based on load flow analysis performed in the MATLAB environment using the Newton-Raphson approach.

The system's overall bus voltages and power flows are next evaluated for the most severe contingency from the contingency list, and to determine a few specific power system contingencies for a 30-bus system. In order to compare the two cases and determine how serious the faults are for the security of the power system, the Newton-Raphson method based power flow will be run as an initial step before those contingencies arise. A branch falling from a generator going off at different times are the scenarios that will be examined. Tables containing the most important system data for each individual case will be used to present the study.

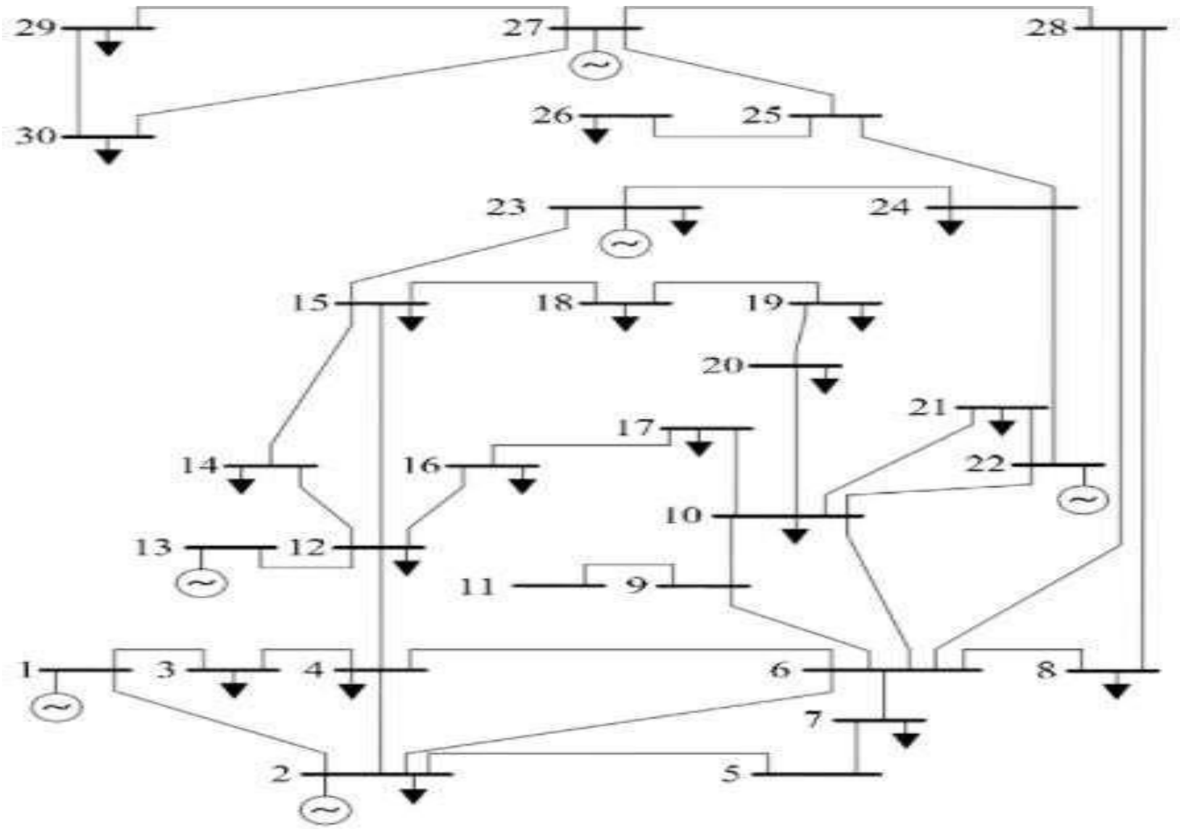

Figure 3.2 IEEE 30 bus system

The IEEE-30 bus system contains 24 PQ buses, 6 PV buses, and 41 lines; therefore, a total of 41 line contingency cases are run for the PIP and PIV calculations. Fig.3.2 shows using the NR technique, the active power in line has been calculated and corresponds to the base case loading condition. The term "pre-contingency condition" is also used to describe this base case analysis, for 41 line contingency case, the load flow is done because the 41 transmission line taking every line outage during a time.

The perform load flow study or analysis is out by taking into consideration each line outage separately. contingencies is done in order of decreasing severity, the results are ranking of contingency to decrease form and computed the outage of just one line by the active power and voltage performance indices.. The greater the value of OPI, which places it first and denotes its greatest severity and greatest danger of instability, the more serious it is. Additionally, it shows that if operating limitations are not maintained, power system operating conditions can exceed acceptable levels, which can seriously harm operations and even result in human losses.

Pre-contingency branch outage power flow solution

Table 3.1 top ten 100% loaded branches and any other branches

Branch No.	Sending End	Receiving End	Normal Rating	Mw Power Flow	MVAr Power Flow	% Loaded Branches (Mw)	% Loaded Branches (MVAr)
10	6	28	32	24.8223	34.8264	77.5697	108.8325
29	21	22	32	19.7775	30.3104	-61.8047	94.7201
30	15	23	16	-8.8053	10.2508	-55.0332	64.0676
16	12	13	65	-37.0000	38.1401	-56.9231	58.6771
22	15	18	16	9.1646	9.1960	57.2787	57.4752
31	22	24	16	-2.0976	8.0761	-13.1098	50.4754
35	25	27	16	-7.4382	7.4678	-46.4885	46.6737
38	27	30	16	7.1224	7.3166	44.5150	45.7288
32	23	24	16	7.0853	7.1402	44.2833	44.6265
37	27	28	16	6.1739	6.3994	38.5868	39.9965

Table 3.2 top ten lowest bus voltages magnitude below 0.95

Bus No.	**Area No.**	**Voltage Magnitude (Pu)**
8	1	0.9606
19	2	0.9653
7	1	0.9674
30	3	0.9679
18	2	0.9684
20	2	0.9692
26	3	0.9722
6	1	0.9732
28	1	0.9747
14	2	0.9767

Table 3.3 top ten highest bus voltages magnitude below 1.05

Bus No.	**Area No.**	**Voltage magnitude (pu)**
1	1	1
2	1	1
13	2	1
27	3	1
23	2	1
22	3	1
21	3	0.9934
25	3	0.9902
24	3	0.9886
12	2	0.9844

Post-contingency branch outage power flow solution (line 2-5 out)

Table 3.4 top ten 100% loaded branches and any other branches

Branch No.	Sending end	Receiving end	Normal Rating	Mw Power Flow	MVAr Power Flow	% Loaded Branches (Mw)	% Loaded Branches (MVAr)
10	6	8	32	24.8231	34.6673	77.5720	108.3352
29	21	22	32	-19.8095	31.3979	-61.9047	98.1183
30	15	23	16	-8.6965	10.3857	-54.3533	64.9109
16	12	13	65	-37.0000	38.3215	-56.9231	58.9561
22	15	18	16	9.2745	9.3084	57.9653	58.1772
31	22	24	16	-2.1719	8.1382	-13.5743	50.8638
35	25	27	16	-7.4093	7.4403	-46.3082	46.5018
38	27	30	16	7.1224	7.3166	44.5150	45.7288
32	23	24	16	7.1910	7.2389	44.9439	45.2429
6	2	6	65	26.5810	27.9878	40.8939	43.0581

Table 3.5 top ten lowest bus voltages magnitude below 0.95

Bus No.	Area No.	Voltage Magnitude (Pu)
7	1	0.9522
5	1	0.9530
8	1	0.9549
19	2	0.9642
6	1	0.9674
18	2	0.9675
30	3	0.9679
20	2	0.9680
28	1	0.9695
26	3	0.9722

Table 3.6 top ten highest bus voltages magnitude below 1.05

Bus No.	Area No.	Voltage Magnitude (Pu)
1	1	1
2	1	1
23	2	1
13	2	1
22	3	1
27	3	1
21	3	0.9931
25	3	0.9902
24	3	0.9886
12	2	0.9844

Post-contingency generator outage power flow solutions (gen 22 out)

Table 3.7 top ten 100% loaded branches and any other branches

Branch No.	Sending end	Receiving end	Normal Rating	MW Power Flow	MVA Power Flow	% Loaded Branches (Mw)	% Loaded Branches (Mva)
10	6	8	32	25.6513	35.0573	80.1604	109.5541
32	23	24	16	9.6509	14.9930	60.3182	93.7060
30	15	23	16	-6.1704	12.9665	-38.5653	81.0405
22	15	18	16	11.0979	12.4015	69.3617	77.5093
35	25	27	16	-11.3819	12.1526	-71.1367	75.9537
31	22	24	16	-8.2270	9.9863	-51.4189	62.4146
16	12	13	65	-37.0000	39.9967	-56.9231	61.5334
21	16	17	16	8.8993	9.8311	55.6208	61.4444
23	18	19	16	7.7181	8.8231	48.2383	55.1445
33	24	25	16	-7.7052	7.8825	-48.1576	49.2658

Table 3.8 top ten lowest bus voltages magnitude below 0.95

Bus No.	Area No.	Voltage Magnitude (Pu)
21	3	0.9325
19	2	09344
20	2	0.9345
22	3	0.9350
17	2	0.9366
10	3	0.9383
18	2	0.9452
9	1	0.9454
11	1	0.9454
8	1	0.9471

Table 3.9 top ten highest bus voltages magnitude above 1.05

Bus No.	Area No.	Voltage Magnitude (pu)
1	1	1
2	1	1
13	2	1
27	3	1
23	2	1
29	3	0.9796
25	3	0.9779
12	2	0.9768
5	1	0.9759
3	1	0.9745

The load flow study or analysis is performed for every outage separately, and calculated for every line of the line outage and generator outage contingencies and one at a time. For each line loss, the Voltage Performance and Active Power Performance indices have been determined. For line outage-1, Fig. no.3.2 displays the bus voltages and active power flows. Table no. 3.3 show the top ten highest bus voltages pre contingency state and after contingency state. Tables 3.6 and 3.9 are both available. Tables 3.1, 3.4, and 3.7 presented both the conditions like pre-contingency state and post-contingency state for the top ten lowest bus voltages, respectively, while Tables 3.2, 3.4, and 3.7 display the same both above contingency state for the top ten highest active power flows. Tables 3.1, 3.4, and 3.7 also show the performance index of the active power and voltage for every line outage, respectively, and also ranked theirs to the highest overall performance index.

According to table 3.3, for that particular line outage, it is highlighted that the first line power failure has the greatest or highest overall PI because of the high value of PIV (because the bus voltages exceeded the maximum voltage limit (1.05 pu), whereas in other outage situations the bus voltages are below or above nominal voltage, i.e. (1 pu), but still fall within the minimum voltage range (0.950 pu), and so PIV can be seen to be above 1.0 based on bus voltages taken into consideration) and as a result, its high ranking is due of this.

3.7 CONCLUSION:

As a result of the analysis, we can say that the severity of every line interruption or outage in the electrical device or power system is determined by the created PI, which show how bad a potential line outage might be. The intensity or severity of that particular line breakdown or outage influences the PI with the highest value, which also indicates that it has the got more chances of moving system parameters outside of their operational range. As a result, it supports the operational engineers of PS to take required and previous actions to minimize the issue and thus improve in guiding to have a safe, secure, reliable and continuous supply from the PS.

CHAPTER 4

BATTERY CAPACITY DETERMINATION FOR THERMAL OVERLOAD ALLEVIATION

4.1 INTRODUCTION

The battery storage must be the right size in order to function as planned. The simple solution is to calculate the capacity using the largest energy amount required by all possible corrective action situations. This approach will give result in a capacity of battery can give the best performance. It may not be cost-effective and also may cause redundant capacity in battery. Thus, the contingency which needs the largest amount of energy may barely exist and may cause mild overload only. Other approach for battery sizing is related to the worst condition. This may not be acceptable due to the worst or severest condition may occur barely and possibly not be required the biggest capacity or produces cascaded blackouts, if not managed within a time. Alternatively, while sizing the battery the contingency severity cannot be the only factor assumed. Along with contingency severity, occurrence probability and potential consequences have to be considered.

An approach of determination of battery capacity is designed and presented with the help of AHP method for battery capacity determination with the help during N-1 contingencies for discharging considering by using severity, probability, and potential consequences of the thermal overload. The method is evaluated for N-1 contingencies on the IEEE 30 Bus System. This approach can also be used in other applications of power system and gives services like load levelling, frequency, reserve, voltage regulations and interruption backup etc. Therefore it is presented an evaluation of the capacity with its important function of alleviation of overload under contingencies.

4.2 BATTERY STORAGE SYSTEMS WITH KEY CHARACTERISTICS

Energy capacity: The amount of energy that can be stored

Rated power capacity: It is the maximum rate of discharge the BESS may reach from a fully charged state or the maximum instantaneous discharge capacity.

Storage duration: Before reducing energy capacity, the time storage might discharge with the power capacity.

Cycle life: The amount of time a battery storage system will give regular discharging and charging before failure.

Self-discharge: It occurs when the battery stored charge is minimized through chemical reactions which is internal or without discharging to do work for the power system grid or for a customer. Self-discharge can be defined as a % of lost in charge over a particular period.

State of charge: It is stated as a percentage and indicates the battery's current state of charge, ranging from completely discharged to fully charge. The battery's ability to offer ancillary services or energy to the grid at any time is controlled by its level of charge.

Round-trip efficiency: It measured as %, the energy charged to the battery divided by energy discharged out of the battery. It shows the total AC-AC and DC-DC efficiency of battery system with inclusion of losses of electrical losses and self-discharge. Though battery manufacturers refer the DC-DC efficiency, efficiency of AC-AC is more important as far as utilities are concerned.

Table 4.1: System of Energy Storage with Applications or services

Roles of ESS	Applications of ESS
Roles with Generation-side	**1. Output smoothing:** ESS is regulated with fast performance in order to absorb more energy during spikes in RG output and release energy, when there is a fall in the power output. **2. Time shift:** Storing extra energy during periods of low-demand and dispatching energy to power system grid during periods of high-demand.

Grid-side roles	**1. Voltage control:** It provides needed reactive power to stable the level in local voltage. **2. Energy load levelling:** It stores cheap energy during off-peak and sell that with more price. **3. Frequency regulation:** It Provides both frequency control in primary and secondary modes by using automatic generation control and droop control. **4. Reserve:** Due to RG outputs for forecast error, ESSs may be used as extra reserves for support in emergency for covering supply and demand mismatch. **5. Transmission utilization efficiency:** The ESS can enhance the capacity of transmission and hence deferring the up gradations in transmission system and therefore the investment costs will be saved. **6. Emergency power supply/black start:** The ESS can restart with condition of shut-down and will be utilized to give energy to under circumstances like a catastrophic breakdown (failure), the power system which is a emergency condition.
Roles in Demand-side	**Vehicle to grid:** The use of batteries in electric vehicle which are considered as a VPP (Virtual Power Plant) in order to supply ancillary services like reserve and frequency regulation and energy time shift. The demand side ESS will be utilized for power quality improvement and reducing the demand charges by storing electricity with cheaper rates to consume for end users at peak periods.

4.3 ANALYTIC HIERARCHY PROCESS (AHP)

The strategy for making decision -AHP is designed in [10], which is widely utilised in several areas in power systems. The algorithm steps are given below.

Step 1: A model- hierarchy, Fig. 4.1 is developed on the basis of the problem of analysis.

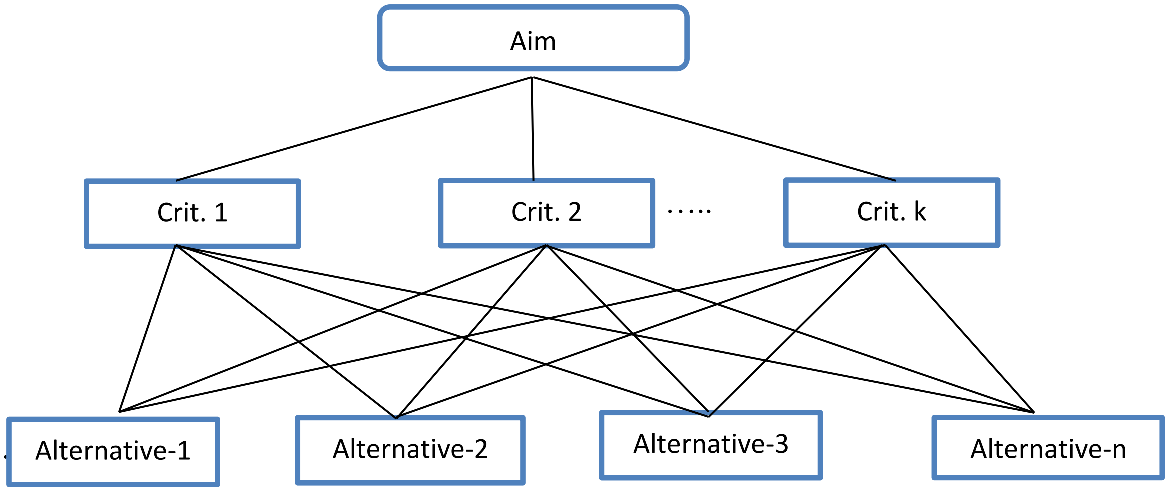

Figure 4.1: A Hierarchy model-3-Level AHP

Step 2: This step starts with the formation of pair-wise comparison matrices at hierarchy model's each level. In the matrix of pairwise comparisons A each component of *A (i, j)* shows the judgement of experts of compared the two's relative importance of *jth* and *ith* factors utilising the technique [10] and [12]. *A(i, j)* is reciprocal for *A(j, i).*

Step 3: For comparison of each in pair element of comparison matrix, the eigen value and related eigen-vector are evaluated. The calculated eigenvector's normalization gives the standardized principal eigenvector along in equivalent to the preferred scales of the components are the elements.

Step 4: Checking in the judgements consistency. Consistency Ratio (CR) and Consistency Index (CI) are valued for every pair-wise comparison matrix that are given in (1), (2).

$$CI = \frac{\lambda_{max.} - n}{n-1} \quad (4.1)$$

Where, n and λmax are the dimension of comparison matrix and max eigenvalue.

$$CR = \frac{CI}{RI} \quad (4.2)$$

Where, Random consistency index (*RI)*. The inconsistency of the judgments is acceptable if the CR is less than 10%; otherwise, the judgments must be corrected.

4.4 METHODOLOGY

The purpose of approach of the battery sizing (capacity) purpose is to mention sizing of the battery which gives support in contingencies to alleviate transmission line thermal overload with severity, probability and potential consequences of N-1 contingencies. Depending on the transmission voltages, the PS can be divided into various sectors, and/or environmental locations that are attached with respect to several zones. Only one battery is located with respect to each power systems area and transferred for each contingency which produces in a particular area, the LTE rating is beyond the thermal overload. The location of the battery capacity is located in each area on bus which is attached to maximum of the overloaded line. In IEEE-30 bus system, the bus with largest sensitivity factor is found. By doing analysis of power supply, redundant power that needs to be injected or absorbed can be finalized at battery siting machine to keep the affected transmission paths or lines load flow within LTE ratings in N-1 contingency and it will be same as related battery size which is required for a certain contingency. It is cleared that the sizes of the battery needed for different contingencies (N-1) can be differed; each contingency should be weighted as mentioned before. It is noted that only those N-1 contingencies which produce excessive heat and need battery corrective actions are chosen and weighted. Also, with annual outage rates are <1of these contingencies, it is assumed unless it is utilized for another auxiliary service, the battery won't be continuously delivered.

4.4.1 Weightings of N-1 Contingencies Using a Hierarchy Model

In order to provide weight to each contingency, there is a structured hierarchy model based on AHP, where four levels are added. The objective is given by top level, i.e. every N-1 contingency is weighted that needs corrective action of battery. The weighing contingencies criteria which are severity of overload, probability of the occurrence and the potential consequences are given by second level. The occurrence probability is calculated by utilizing the accessible data like every components permanent failure ratio in transmission system. The overload severity is defined as percentage of LTE rating which is given as:

$$\text{Severity of Overload } = \frac{\text{Load flow} - \text{LTE}}{\text{LTE}} \times 100\% \tag{4.3}$$

It is noted that there is a consideration and measurement of the overload which disrupts the rating (LTE) and needs the helpful action of battery. The level of third determines the Sub-criteria for calculating the consequences which are potential, if there is no contingency alleviation within 15 minutes, in turn there may be tripped out in overloaded line, which other lines will be overloaded, and can be resulted in blackouts which can be cascaded. Two criterias are selected to consequences quantification: 1) the overload average which is defined as % of ratings (LTE) and 2) nos. of overloaded lines

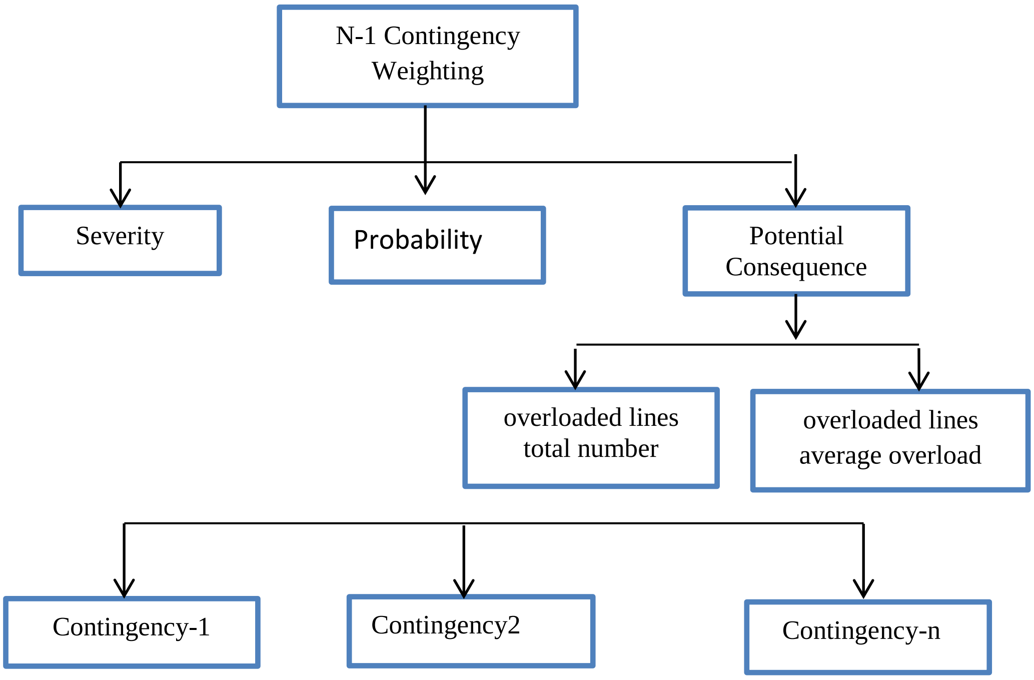

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Figure 4.2: weightings of N-1 contingencies-Hierarchy model

Load flow analysis determines severity, probability and potential consequence. These can be stated as %s. The third level sub criteria last condition of excessed or overloaded lines number and average overload are provided with 50% parallel weighting.

The relative weighting of severity, probability, and potential consequence is calculated by the AHP method by formation of a comparison matrix. The probability is given as the most characteristic among other 3 characteristics due to coping of the battery with many contingencies. Compared to severity of contingency, the potential is considered as important, because this contingency does not produce overload which can be severe, it is more significant because it could have a severe effect, and requires relatively more attentions than one causing significant overload but not potential consequence which can be severe. Because in determination of battery capacity these 3 characteristics are having importance, scales of small ratio are elected. Therefore the comparison matrix PC is shown as follows:

$$\text{PC} = \begin{array}{c} \\ Pro \\ Sev \\ PotCon \end{array} \begin{array}{c} \begin{array}{ccc} Pro & Sev & PotCon \end{array} \\ \begin{pmatrix} 1 & 3 & 2 \\ \frac{1}{3} & 1 & \frac{1}{2} \\ \frac{1}{2} & 2 & 1 \end{pmatrix} \end{array} \tag{4.4}$$

The scales of resulting priority are obtained as 16.34%, 53.96%, and 29.7% for severity, probability, and potential consequence by calculating the eigenvector of PC. Finally, multiplying sub-criterion priority by each contingency weighting and criterion and adding the resulting weightings of every contingency which presents each contingency's final composite weighting.

4.4.2 Battery Capacity Determination

There are two categories in corrective actions of battery i.e. charge and discharge and the larger battery sizing needed to handle these conditions. N-1 contingencies which need helpful actions in the battery are divided by two main types, requiring charge and discharge activities. The contingencies composite weightings are maintained through normalization in such a way that the sum of changed contingencies weightings in each category is equal to 1(i.e. = 1), which are mentioned as follows:

$$w_a^i = w_{pa}^i / \sum_{i=1}^{j} w_{pa}^i , \qquad i = 1, 2, 3, \ldots, j \tag{4.5}$$

$$w_a^i = w_{pa}^i / \sum_{i=j+1}^{n} w_{pa}^i , \qquad i = j+1, \ j+2, \ldots, n \tag{4.6}$$

Where, contingency 1 – *j* and *j+1-n* need charging and discharging actions, w_a^i- *ith* contingency adjusted composite weighting and w_{pa}^i- *ith* contingency weighting of pre-adjustment composite.

Battery corrective action should be maintained for 20 minutes, assuming that the implementation of pre-defined permanent steps take 20 minutes to take effect. Additionally, the storage or battery efficiency which is round-trip is 80%. The needed capacity of charging/discharging of every prison or corrective action is measured as the multiplication of the calculated power requirement by 20 minutes, which is divided by 80% efficiency. Therefore, the capacities of discharging and charging are formed by evaluating each group of contingencies the weighted average which is mentioned as follows:

$$C_c = w_a^1 E_c^1 + w_a^2 E_c^2 + \ldots + w_a^j E_c^j \quad (4.7)$$

$$C_d = w_a^{j+1} E_c^{j+2} + w_a^{j+2} E_c^{j+2} + \ldots + w_a^n n \quad (4.8)$$

where E_c^i - *ith* contingency charging capacity and E_d^1 -discharging capacity.

The battery capacity *C* can be calculated by summing up of $C_c$and C_d, as

$$C = C_c + C_d \quad (4.9)$$

Equation (4.7) gives the battery with the ability to adjust with contingencies which need either discharging or charging corrective actions. But, both actions of discharging and charging are not equally important as far as thermal overload alleviation produced by (N-1) contingencies are concerned, for the contingencies total complex weightings in discharge and charge pairs are different. Other method will be to sum weightings to the evaluated C_c and C_d capacities ago adding them up which are mentioned as follows:

$$C = w_c C_c + w_d C_d \quad (4.10)$$

Where, *wc* and *wd* are two weightings which are calculated by the comparative importance of contingencies of two groups of as

$$w_c : w_d = \sum_{i=1}^{j} w_{pa}^i : \sum_{i=j+1}^{n} w_{pa}^i \quad (4.11)$$

The *wc*+*wd* = 2 permits the battery to react with contingencies which need actions of either discharge or charge.

This method modifies the ratios of charging and discharging capacity inside the battery. There are check on both methods and tested with IEEE-30 Bus System.

4.4.3 Use of Battery Energy Storage or Corrective Control Action

The goal of these operating rules is that the power system should remain secure. That is, all equipment is operating below normal ratings and contingency analysis programs determine that, even with a major generating station or bulk transmission circuit out of service, no equipment exceeds its long-time emergency rating. Should the system be found not to be "secure," then the operator must take action to restore system security. The type of action and the speed with which it is to be implemented depend on the severity of the equipment overloads [13].

The effectiveness of the corrective action depends on how fast the action can be implemented to reduce the power flow of the overloaded circuit to a value below its normal continuous rating. For instance, if generation re-dispatch is considered, due to the ramp down/up limit of generators, it may take several minutes to move back the power flow on the affected circuit below the thermal rating. Therefore, the transmission limit to be applied in the pre-contingency condition (preventive action) must be defined so that if the contingency occurs, the power flow on the affected circuit does not surpass the LTE or STE rating, depending on the reliability criterion applied.

A battery could be connected at either the receiving or sending end of the affected circuit to absorb/inject power to immediately reduce the power flow over that circuit. In that way, the transmission limit for pre-contingency conditions could be increased. If the fault occurs, the battery is controlled to prevent the power flow exceeding the STE rating for the first minutes. The operator then initiates the permanent mitigation measures (generation re-dispatch, start-up of a fast unit, phase shifter control, etc.). After several minutes, these actions take effect reducing the power flow over the line. The battery action is no longer required, and consequently the charging/discharging process stops. Hence, a battery in this role will not replace but complement the control actions of other measures to further increase the transmission capability of critical transmission corridors. Boosting the transmission capacity of certain transmission paths has a significant impact on system operation cost, because it may permit higher dispatch of inexpensive generation.

4.5 Test Results

The two approaches (4.9) and (4.10) were tested on the IEEE 30 test case system is used with 6 load buses (PQ) and 24 regulated buses (PV), and 41-lines as presented in Figure 3.2. MATPOWER 7.1 is used to perform the analysis of power flow in each N-1 contingency, giving two congestion points (bus 8 and 21), with 1/area, and at each point, a battery is sited. Ten N-1 contingencies are producing thermal overload which violates LTE ratings of which two need the battery corrective or prison actions at bus 8 bus and bus 21. The two contingencies are performing the single transmission lines outage from 6th to 8th bus and 21 to 22. Both of them need actions of charging and discharging. By taking different capacities for those branches and then selecting the one best capacity for those branches.

The power flow analysis under every N-1 contingency was performed in MATLAB using MATPOWER 7.1, which gave two congestion points (bus 8 and 21) and a battery was sited at each point. Ranked the top ten N-1 contingencies causing thermal overload violating LTE ratings, of which two require the corrective actions of battery at bus 8 and the rest requires the battery at bus 21. The battery is injected at the sending end of the line. At bus 8, five different sizing of battery are hit and trail and among them one suitable is selected to alleviate thermal overload on branch 10 (bus 6 to 8). A capacity of 15 MWh is enough for the battery at bus 8 to alleviate the thermal overload. Similarly, bus 21, five different sizing of battery are hit and trail and among them one suitable is selected to alleviate thermal overload on line 29 (bus 21 to 22). A capacity of 75 MWh is enough for the battery size at bus 21 to bring the load flow within LTE ratings are demonstrated in Table 4.5.

Table 4.2 Multiple Battery capacity applied at bus 8

Branch No.	Sending end	Receiving end	Without Battery		Applied Battery Capacity	With Battery	
			MW flow	MVAr flow		MW flow	MVAr flow
10	6	8	24.8223	24.4281	5 MW	20.4690	24.3457
					10 MW	16.1198	24.2793
					15 MW	11.7747	24.2287
					20MW	7.4336	24.1937
					25 MW	3.0965	24.1743

Table 4.3 top 10 branches after applied battery at bus 8

Branch No.	Sending end	Receiving end.	Normal Rating	Without Battery (MW Flow)	Without Battery (MVAr Flow)	With Battery (MW Flow)	With Battery (MVAr Flow)
10	**6**	**8**	**32**	**24.8223**	**24.4281**	**11.7747**	**24.2287**
29	21	22	32	-19.7775	-22.9689	-19.7776	-22.3682
30	15	23	16	-8.8053	-5.2484	-8.9616	-5.0272
16	12	13	65	-36.9999	-9.2558	-36.9999	-9.0077
22	15	18	16	9.2745	9.3084	12.2599	-0.8372
31	22	24	16	-2.0976	7.7989	-2.0976	7.7989
35	25	27	16	-7.4093	7.4403	-13.2221	2.5717
38	27	30	16	7.1224	1.6746	7.1224	1.6746
32	23	24	16	7.0853	0.8838	6.9285	0.9608
6	2	6	65	20.2751	7.4217	15.4817	7.5773

Table 4.4 Multiple Battery capacity applied at bus 21

Branch No.	**Sending end**	**Receiving end**	**Without Battery**		**Applied Battery Capacity**	**With Battery**	
			MW flow	**MVAr flow**		**MW flow**	**MVAr flow**
29	21	22	-19.7775	-22.9689	40 MW	-3.7333	-19.6249
					45 MW	-1.7223	-19.3282
					50 MW	0.2899	-19.0580
					60 MW	4.3191	-18.5959
					70 MW	8.3545	-18.2374
					75 MW	10.3747	-18.0966

Table 4.5 Top 10 branches after applied battery at bus 21

Branch No.	**Sending end**	**Receiving end**	**Normal Rating**	**Without Battery (MW Flow)**	**Without Battery (MVAr Flow)**	**With Battery (MW Flow)**	**With Battery (MVAr Flow)**
10	6	8	32	24.8223	24.4281	23.3666	24.7169
29	**21**	**22**	**32**	**-19.7775**	**-22.9689**	**8.3544**	**-18.2373**
30	15	23	16	-8.8053	-5.2484	-14.2053	-3.9105
16	12	13	65	-36.9999	-9.2558	-36.9999	-12.9332
22	15	18	16	9.1646	0.7597	4.57511	3.0654
31	22	24	16	-2.0976	7.7989	10.6235	0.2825
35	25	27	16	-7.4381	-0.6645	-0.2505	-4.9745
38	27	30	16	7.1223	1.6746	7.1224	1.6746
32	23	24	16	7.1910	7.2389	1.5673	4.0893
6	2	6	65	20.2751	7.4217	0.1722	10.5007

4.6 CONCLUSION

AHP and power flow analysis are used to find the battery capacity which provides support for N-1 contingencies for alleviation of transmission lines thermal overload. Power flow analysis improvement installed capacitor bank plays as important role in power system improvement which not only reduces the total system generation cost and losses but also improve the system efficiency. The corrective actions effectively removed the limit violations in the system. Battery storage systems play a key role to improve the reliability of power system in contingency states. Power flow analysis is used to determine the capacity of the battery providing support during N-1 contingencies to alleviate thermal overload of transmission lines.

CHAPTER-5

CONCLUSION AND SCOPE FOR FUTURE WORK

5.1 CONCLUSIONS

Chapter 3 evaluates two significant performance indices, to select and rank the contingencies that are crucial for contingency analysis, use the active and reactive power performance index (PIP& PIV). These indices were calculated using the Newton-Raphson load-flow method for a variety of test bus systems because the contingency rankings are determined using the overall performance index (OPI), which is the combination of the active power and voltage performance indices, two severity indices.

In Chapter 4, two AHP-based approaches to determining battery capacity were proposed. They were evaluated using an IEEE 30 Bus System. When determining the total battery capacity given the proposed charging and discharging capabilities, the difference between these two methods is whether or not the relative importance of charging and discharging corrective actions is taken into account. In terms of system security and the percentage of manageable contingencies focused on the worst case situation, both of these two approaches were shown to be better. However, if energy storage is expected to support not only contingency thermal overload alleviation but also other power grid operations, the system will require more storage capacity to be distributed in the network with a suitable dispatch strategy in order to effectively support the system and achieve cost savings.

5.2 SCOPE FOR FUTURE WORK

The proposed algorithms and methodologies have a number of limitations that are discussed in the thesis and should be solved in future work.

- To carry out the contingency analysis and selection while estimating multiple kind or types of equipment or line failures.
- It is not optimal, when battery sizing of the system is considered for the corrective actions taken after a contingency. As a result, in the upcoming, the size of the system for battery storage should be created utilising optimization techniques and taking into account the numerous operational supports for power systems that battery storage can supply.

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APPENDIX-A

The following tables summarize the description of a modified IEEE 30-bus system as introduced in [1].

Table A.1:

Generator Data of IEEE-30 Bus System

Bus No.	V_G^O	P_G^O	P_G^{min}	P_G^{max}	Q_G^{min}	S_G^{max}	Cost. Coefficient		
	(pu)	(MW)	(MW)	(MW)	(MVAR)	(MVAR)	a	b	c
1	1.05	23.54	50	200	-20	250	0.0	2.0	0.00375
2	1.045	50.00	20	80	-20	100	0.0	1.75	0.0175
5	1.01	20.00	15	50	-15	80	0.0	1.0	0.0625
8	1.01	20.00	10	35	-15	60	0.0	3.25	0.00834
11	1.05	20.00	10	30	-10	50	0.0	3.0	0.025
13	1.05	20.00	12	40	-15	60	0.0	3.0	0.025

The bus data and line data has been given in Table A.1 and A.2 respectively.

Table A.2

Bus Data of IEEE-30 Bus System

Bus No.	Voltage		Generation		Load	
	Mag(pu)	Ang(deg)	P(MW)	Q(MVAr)	P(MW)	Q(MVAr)
1	1	0	23.54	0.0	0.0	0.0
2	1	0	60.97	0.0	21.70	12.70
3	1	0	0.0	0.0	2.40	1.20
4	1	0	0.0	0.0	7.60	1.60
5	1	0	0.0	0.0	0.0	0.0
6	1	0	0.0	0.0	0.0	0.0
7	1	0	0.0	0.0	22.80	10.90
8	1	0	0.0	0.0	30	30
9	1	0	0.0	0.0	0.0	0.0
10	1	0	0.0	0.0	5.80	2
11	1	0	0.0	0.0	0.0	0.0
12	1	0	0.0	0.0	11.20	7.50
13	1	0	37	0.0	0.0	0.0
14	1	0	0.0	0.0	6.20	1.60
15	1	0	0.0	0.0	8.20	2.50
16	1	0	0.0	0.0	3.50	1.80
17	1	0	0.0	0.0	9	5.80

18	1	0	0.0	0.0	3.20	0.90
19	1	0	0.0	0.0	9.50	3.40
20	1	0	0.0	0.0	2.20	0.70
21	1	0	0.0	0.0	17.50	11.20
22	1	0	21.59	0.0	0.0	0.0
23	1	0	19.20	0.0	3.20	1.60
24	1	0	0.0	0.0	8.70	6.70
25	1	0	0.0	0.0	0.0	0.0
26	1	0	0.0	0.0	3.50	2.30
27	1	0	26.91	0.0	0.0	0.0
28	1	0	0.0	0.0	0.0	0.0
29	1	0	0.0	0.0	2.40	0.90
30	1	0	0.0	0.0	10.60	1.90

Table A.3

Line Data of IEEE-30 Bus System

From Bus	To Bus	R(pu)	X(pu)	B(pu)	Rting (MVA)
1	2	0.02	0.06	0.03	130
1	3	0.05	0.19	0.02	130
2	4	0.06	0.17	0.02	65
3	4	0.01	0.04	0.00	130
2	5	0.05	0.20	0.02	130
2	6	0.06	0.18	0.02	65
4	6	0.01	0.04	0.00	90
5	7	0.05	0.12	0.01	70
6	7	0.03	0.08	0.01	130
6	8	0.01	0.04	0.00	32
6	9	0.00	0.21	0.00	65
6	10	0.00	0.56	0.00	32
9	11	0.00	0.21	0.00	65
9	10	0.00	0.11	0.00	65
4	12	0.00	0.26	0.00	65
12	13	0.00	0.14	0.00	65
12	14	0.12	0.26	0.00	32
12	15	0.07	0.13	0.00	32
12	16	0.09	0.20	0.00	32
14	15	0.22	0.20	0.00	32
16	17	0.08	0.19	0.00	16
15	18	0.11	0.22	0.00	16
18	19	0.06	0.13	0.00	16
19	20	0.03	0.07	0.00	16
10	20	0.09	0.21	0.00	32
10	17	0.03	0.08	0.00	32
10	21	0.03	0.07	0.00	32
10	22	0.07	0.15	0.00	32
21	22	0.01	0.02	0.00	32

15	23	0.10	0.20	0.00	32
22	24	0.12	0.18	0.00	16
23	24	0.13	0.27	0.00	16
24	25	0.19	0.33	0.00	16
25	26	0.25	0.38	0.00	16
25	27	0.11	0.21	0.00	16
28	27	0.00	0.40	0.00	16
27	29	0.22	0.42	0.00	65
27	30	0.32	0.60	0.00	16
29	30	0.24	0.45	0.00	16
8	28	0.06	0.20	0.02	32
6	28	0.02	0.06	0.01	32

APPENDIX-B

MATPOWER

1. INTRODUCTION

Power system optimizations become important that make system operator can operate at lower cost. Also, power system securities are included in solving process. MATPOWER is a powerful MATLAB [1] programming package providing for power flow and optimal power flow solving. However power system optimization problems are more complication and diversity when additional constraints are considered. Thus the heuristic algorithm optimization is required. If we can apply MATPOWER into the new heuristic algorithms, the convenient solving should be occurred. Several author researches that related with applied MATPOWER in the process of optimal finding have been published. Such in [3], optimal micro grid system and influence in distribution system are studied. Power flow calculation by applied MATPOWER is encounter into objective function evaluation process. In [4], optimal multitype distributed generators (DGs) placement is solved. Applied MATPOWER is taken into objective function of multi-objective optimization NSGA-II for power system loss calculation. In [5], distribution system including DGs reconfiguration is considered for loss reduction. Power flow analysis by applied MATPOWER is used for finding the system power loss of objective function. Also in [6], the optimal line automatic voltage regulation (AVR) placement and tap setting in distribution has been proposed. Moreover in [7], the hybrid of loss sensitivity factor and particle swarm optimization (PSO) is used to find the optimal DG placement. These all author researches [3-7] use applied MATPOWER in the objective function for finding the system loss and voltage profile.

2. MATPOWER

MATPOWER is an open source programming package for power flow analysis and optimal power flow (OPF). It is developed by Power System Engineering Research Center (PSERC). The present volume is V. 1.14. Although MATPOWER requires running on licensing computer language MATLAB, convenient programming development is interesting. The process of MATPOWER comprises of three steps.

Step 1: input file, the power system data such bus data, branch data and generator fuel cost function will be read for next step.

Step 2: the power flow is calculated by Newton-Raphson method (default method).

Step 3: all results display in step 1, the input data is prepared. There is specified in a set of matrices package as a fields of a MATLAB structure, referred to as “MATPOWER case” structure. This structure is typically defined in a case file; see CASEFORMAT for details on the case file format.

APPENDIX-C

ENERGY STORAGE TECHNOLOGY

C.1 STORAGE TYPES

Energy storage devices can be categorized as mechanical, electrochemical, chemical, electrical, or thermal devices, depending on the storage technology used (Figure 1.1). Mechanical technology, including pumped hydropower generation, is the oldest technology. However, a limitation of this technology is its need for abundant water resources and a different geographic elevation, as well as the construction of power transmission lines to households that consume electricity. Recently, transmission-line construction cost has surpassed the cost of installing a pumped hydropower generation facility.

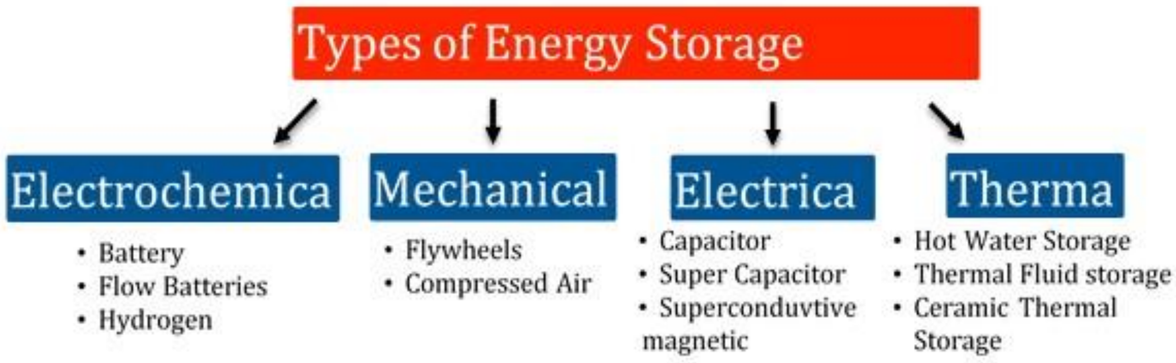

Figure C.1: Classification of Energy Storage

In addition to the recent spread of mobile information technology (IT) devices and electric vehicles, the increased mass production of lithium secondary batteries and their lowered costs have boosted demand for energy storage devices using such batteries. Lithium secondary batteries convert electric energy to chemical energy, and vice versa, using electrochemical technologies. Such technologies also include lead storage batteries and sodium–sulfur batteries. Chemical technologies include energy storage technologies such as fuel cells, and mechanical technologies include electric double-layer capacitors. The performance of energy storage devices can be defined by their output and energy density. Their use can be differentiated by place and duration of use, as defined by the technology adopted. In Figure C.2, the applications (in the tan-colored boxes) are classified according to output, usage period, and power requirement, and the energy storage devices (in the amber-colored boxes) according to usage period, power generation, and system and/or network operation.

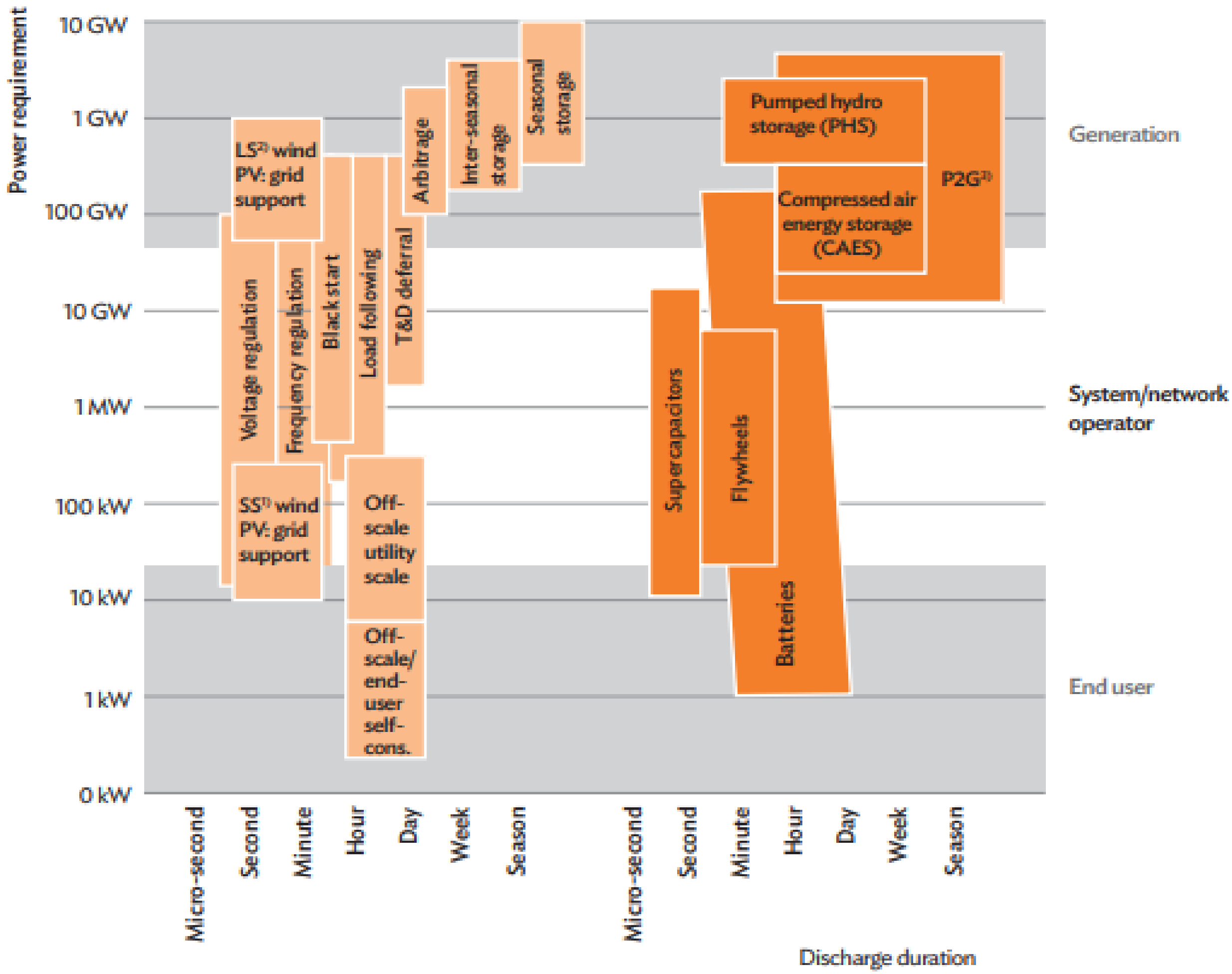

Figure C.2: Different Technology for Different Purpose

C.2 TECHNICAL REQUIREMENTS

C.2.1 Round-Trip Efficiency: Round-trip efficiency takes into consideration energy losses from power conversions and parasitic loads (e.g., electronics, heating and cooling, and pumping) associated with operating the energy storage system. This metric is a key determinant of the cost-effectiveness of energy storage technologies. Among energy storage options, compressed-air energy storage (CAES) has the lowest reported efficiency (40%–55%), and Li-ion batteries have the highest (87%–94%). For energy storage coupled with photo voltaics, efficiencies of less than 75% are unlikely to be cost effective.

C.2.2 Response Time: The need for fast response times is expected to be more important for variability-damping than for load-shifting applications, and hence more relevant to utility-scale photovoltaic generation in this evaluation. Passing clouds are the primary source of rapid changes in photovoltaic power output. Solar insolation at a single point can change by more than 60% in seconds. Changes of this magnitude in power output from utility-scale photovoltaic systems are expected to occur within minutes. Photovoltaic power output ramp rates were measured over a year at a photovoltaic system in Hawaii that operated at 50% capacity. In that study, only 0.07% of the one-minute ramps were operating at greater than 60% capacity and only 5%, at greater than 10% of that capacity. System operator experience suggests that a response time of seconds would be adequate to dampen short-term variability events of significant magnitude.

C.2.3 Lifetime and Cycling: As is the case for efficiency, the cost-effectiveness of energy storage is directly related to its operational lifetime. The lifetime of an ESS depends on many factors, including charge and discharge cycling, depth of discharge, and environmental conditions. For any application, maximizing the depth of discharge minimizes the required energy storage capacity. The cycling schedule thus offers the greatest degree of freedom in design. For residential and commercial applications, one or two cycles per day or 7,300-22,000 lifetime cycles would be adequate to allow for photovoltaic power shifting and nighttime storage of cheap grid electricity. Increasing the magnitude or percentage of power spikes that is tolerated without intervention would also reduce the lifetime cycling requirement. An energy storage system that is designed to respond to power spikes that are more than 10% of the photovoltaic nameplate power in a single charge and discharge cycle might experience many more than 100,000 cycles over its lifetime, especially in cloudier locations.

C.2.4 Sizing

Frequency regulation and black start BESS grid applications are sized according to power converter capacity (in MW). These other grid applications are sized according to power storage capacity (in MWh): renewable integration, peak shaving and load leveling, and microgrids.

Table c.1 Sizing Methods for Power and Energy Applications

Sized by power converter capacity [MW]	Sized by power storage capacity [MWh]
Frequency regulation, black start	Renewable integration, peak shaving and/or load leveling, microgrids

M.E. Thesis

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