Islanding Scheme and Auto Load Shedding to Protect Power System

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***Abstract*—** Abnormal condition in a power system generally leads to a fall in system frequency, and it leads to system blackout in an extreme condition. This paper presents a technique to develop an auto load shedding and islanding scheme for a power system to prevent blackout and to stabilize the system under any abnormal condition.

In this paper, load shedding is done calculating the rate at which the system frequency is varying during an abnormal condition. The rate of change of frequency (rocof) technique proposes the sequence and conditions of the applications of different load shedding schemes and islanding strategies. It is developed based on the international current practices. It is designed, and an auto load-shedding and islanding scheme is developed which is quick and is highly helpful in obtaining system stability when compared to existing load shedding scheme(traditional scheme). The effectiveness of the developed scheme is investigated ,simulating different abnormal conditions in Matlab and the results are analysed. The proposed model work better when compared to old existing models.

***Keyword*—**Auto load-shedding, islanding, rate of change of frequency, under frequency load shedding

I. Introduction

RELIABLE and secure operation of large power systems has always been a primary goal for system operators. Power-load unbalance is the most dangerous condition for power system operation. Every unbalance between generation and load causes a deviation of the frequency from its steady state which - if not properly counteracted - can lead to system black-out. Emergency load-shedding for preventing frequency degradation is an established practice all over the world. A rolling blackout, also referred to as load shedding, is an intentionally engineered electrical power shutdown where electricity delivery is stopped for non-overlapping periods of time over different parts of the distribution region. The objective of load shedding is to balance load and generation. Since the amount of overload is not known at the instant of disturbance, the load is shed in blocks until the frequency stabilizes. The main features that a load shedding scheme must provide are : The action has to be quick, so that the frequency drop is halted before a situation of danger has occurred. A protection scheme should have following features [1]:

- Unnecessary actions have to be avoided
- The protection system has to be liable and redundant, as a malfunction of it would surely lead to a major failure of the whole system.
- The amount of load to be shed should always be the minimum possible, but anyway sufficient to restore the security of the grid and to avoid the minimum allowable frequency being overcome.

Different techniques are available for implementing the load shedding scheme. The three main categories of load shedding schemes are:

1) Traditional. 2) Semi-adaptive. 3) Adaptive.

The **Traditional load shedding** is definitely the most diffused, because it is simple and it does not require sophisticated relays, such as ROCOF relays[1]. The traditional scheme sheds a certain amount of the load under relief when the system frequency falls below a certain threshold. This first shed may be insufficient; in that case, if the frequency keeps on falling down, further sheds are performed when lower thresholds are passed. The values of the thresholds and of the relative amounts of load to be shed are decided off-line, on the base of experience and simulations. The **Semi-adaptive** scheme provides a step forward. The semi-adaptive load shedding scheme uses the frequency decline rate as a measure of the generation shortage. The activation of this scheme depends on the rate of change of frequency (ROCOF) when the system frequency reaches a certain threshold. According to the value of ROCOF, a certain amount of load is shed. That is, this scheme checks the speed at which the threshold is exceeded: the higher the speed, the more load is shed. The next improvement in load-shedding is the so called **Adaptive method** which makes use of the frequency derivative and is based on the SYSTEM FREQUENCY RESPONSE (SFR) model. Sometimes, blackout can be prevented in real time through controlled disintegration of a system into a number of islands together with generation tripping and/or load shedding .Disintegrating a grid system into a number of islands can be considered either as a last resort or as a primary measure. The basis for islanding is never unique and depends upon the utility in particular.

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II. Proposed Technique

Abnormal condition in a power system generally leads to a fall in system frequency. The usual solution to rescue the system from this sort of state is the load shedding. However, in some cases the load shedding may be unnecessary as the system makes itself stable by providing additional input from its stored kinetic energy or from the spinning reserve or by lowering the system frequency within acceptable limit. In some cases, the magnitude of load shedding may be inappropriate, that is more or less than required, to make the system stable by maintaining the system frequency within acceptable range. In some cases, only load shedding cannot rescue the system from total collapse. In that case, the system may be disintegrated into a number of islands.

The main advantages of islanding are

1) Easier to minimize generation-load imbalance in an island than that in a large integrated system and

2) Quicker to restore the system by integrating the islands than restoring the whole system from a blackout state[2].

The technique proposed in this paper is a heuristic one that considers all these issues and develops a comprehensive solution to the instability of a power system[5][6]. The technique is based on three schemes:

1) Traditional load shedding 2)Semi-adaptive load shedding 3)Disintegration of grid The traditional load shedding scheme is implemented through FS relays. The scheme is activated only when the system frequency, falls below a certain threshold value, f_{TH} the implementation of other schemes requires FD relays.

A. Sequential Steps:

The proposed scheme is implemented in steps, sequentially. The activation of number of steps depends on the state of the system. Different steps of the technique are as follows.

Step 1. System frequency and ROCOF are continuously monitored by FS and FD relays, respectively.

Step 2. The traditional load shedding scheme is activated if f<f_{TH} and |df/dt| <mo. The ROCOF based load shedding scheme is activated instead of traditional one ,if f<f_{TH} and mo<df/dt<M.mo and M are ROCOF related threshold values. the magnitude of M is much bigger than mo. Grid disintegration scheme is activated only when f<f_{TH} and ROCOF exceeds M. That is, disintegration scheme is implemented if f<f_{TH} and |df/dt|< M

Step 3. The system starts measuring time once the ROCOF based load shedding is activated. After the preset time delay (TD),K1 , if the system frequency is still below the threshold value, f_{TH}, the traditional load shedding scheme is activated.

The system frequency is checked after another preset TD, K2 , where K2 is greater than K1. At this time, if the system frequency is lower than , and ROCOF is negative, then disintegration scheme is activated.

Step 4. Once the disintegration of grid scheme is implemented, generation is adjusted appropriately in each island if the islanded system frequency is higher than the rated. If in an islanded system f<f_{TH} and *|df/dt|*< *mi* , traditional load shedding scheme is activated. Here, *mi* is the rate of change of frequency related threshold value of the th island. However, if f<f_{TH} and |df/dt|< *mi* and ,then the ROCOF based load shedding scheme is activated

Step 5. After implementing ROCOF based load shedding in Fig 1:Sequential steps of proposed technique island, if the elapsed time is more than the preset TD *k3*, and the frequency is still less than threshold value the traditional load shedding scheme in that island is activated.

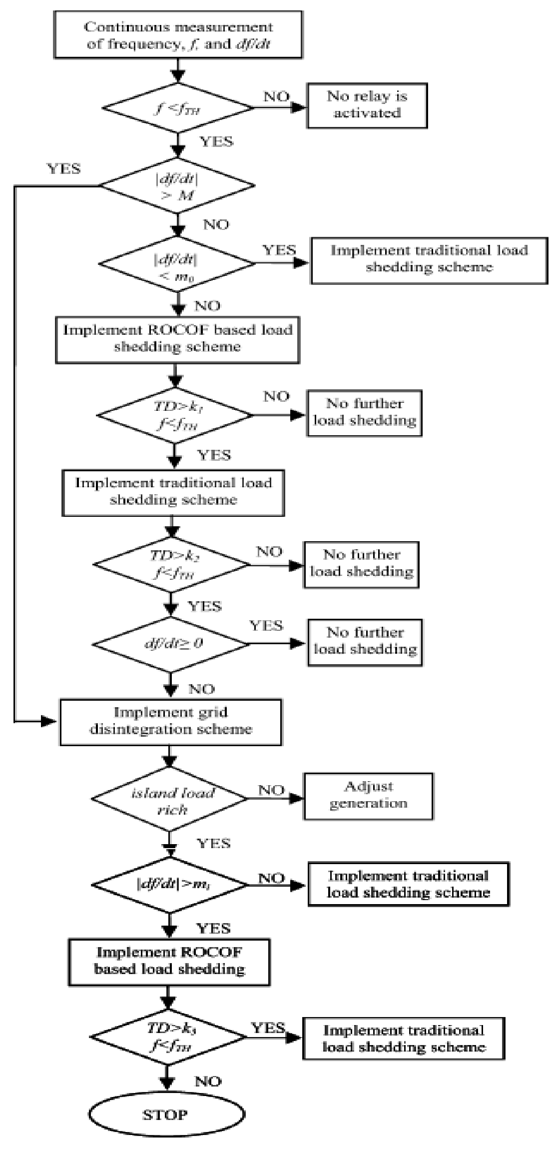

Fig. 1 Sequential steps of proposed technique

B. Determination of Threshold Values:

The first frequency threshold, , is a limiting frequency state of a power system. That is, the system cannot return to steady state condition without any load shedding relay activation if the frequency drops below. The equipment that are more sensitive to frequency drops are generators, auxiliary services, and steam turbines[3] [4] . Auxiliary services of a power plant are more demanding than generators in terms of minimum allowable frequency; in fact, they begin to malfunction at a frequency of 47.5 Hz (57 Hz in case of 60 Hz system), while the situation becomes critical, creating cascade effect, at about 46–44 Hz (55–53 Hz in 60 Hz system).

The first step of the algorithm is estimating the total load mismatch between the generated power and load power. This can be determined as follows. For a single machine, the swing equation is given by

$$\frac{2H}{f_0}\frac{df}{dt} = P_m - P_e = P_{diff} \tag{1}$$

Where, f_0 is the nominal frequency of the system and P_{diff} is the difference in the generated power and the load power

The inertia constant H for each machine is represented as ***H1*** , ***H2*** , ***H3***…. ***Hn*** . The mechanical shaft power and the electrical power for each machine is represented as ***Pm1*** , ***Pm2*** , ***Pm3*** …. ***Pmn*** and ***Pe1*** , ***Pe2*** , ***Pe3*** ….. ***Pen*** .The swing equations for each individual machine are;

$$\frac{2H_1}{f_0}\frac{df_1}{dt} = P_{a1} = P_{m1} - P_{e1} \text{ For machine 1} \tag{2}$$

$$\frac{2H_2}{f_0}\frac{df_2}{dt} = P_{a2} = P_{m2} - P_{e2} \text{ For machine 2} \tag{3}$$

$$\frac{2H_3}{f_0}\frac{df_3}{dt} = P_{a3} = P_{m3} - P_{e3} \text{ For machine 3} \tag{4}$$

And so on

$$\frac{2H_n}{f_0}\frac{df_n}{dt} = P_{an} = P_{mn} - P_{en} \text{ For machine n} \tag{5}$$

The equivalent inertia constant of the two machines is the summation of the individual inertias of each machine.

$$H_{eq} = \Sigma \textit{individual inertias of each machine for all the machines in system}$$

Also, the equivalent mechanical and electrical powers are given as;

P_m = Σ individual mechanical shaft power of each machine for all the machines in the system

Pe =Σ individual electrical power of each machine for all the machines in the system

The QV analysis is carried out in the following manner. The equations for active and reactive power are,

$$P_i = \sum_{j=1}^{n} V_i V_j Y_{ij}^* \cos(\delta_{ij} - \theta_{ij}) \tag{6}$$

$$Q_i = \sum_{j=1}^{n} V_i V_j Y_{ij}^* \sin(\delta_{ij} - \theta_{ij}) \tag{7}$$

On simplifying it further for a two bus system the equations will be;

$$P_{12} = |V_1|^2 G - |V_1||V_2|G * \cos(\delta_{12}) + |V_1||V_2|B * \sin(\delta_{12}) \tag{8}$$

$$Q_{12} = |V_1|^2 G - |V_1||V_2|B * \cos(\delta_{12}) - |V_1||V_2|G * \sin(\delta_{12}) \tag{9}$$

Now at the receiving end the power delivered is

$$P_D = -P_{12} \textit{ and } Q_D = -Q_{12} \tag{10}$$

Hence the QV curves are plotted for given values of ***PD*** and ***V2*** to compute ***θ 12*** and from this the value of ***QD*** is calculated from the second equation. Although this is only for a two bus system, the same procedure is followed for a larger system

Now once the equation between ***QD*** and ***V2*** is established, differentiating the above equation we get,

$$\frac{dQ_D}{dV_2} = V_2 * B\cos\delta_{12} + V_2 * G\sin\delta_{12} \tag{11}$$

This is for a two bus system. For a n bus system the generalized equation is,

$$\frac{dQ_i}{dV_i} = \sum_{j=1}^{n} V_j Y_{ij}^* \sin(\delta_{ij} - \theta_{ij}) \tag{12}$$

Thus individually for each bus the relation dQ/dV relation can be written as;

$$\frac{dQ_1}{dV_1} = \sum_{j=1}^{n} V_j Y_{1j}^* \sin(\delta_{1j} - \theta_{1j}) \tag{13}$$

$$\frac{dQ_2}{dV_2} = \sum_{j=1}^{n} V_j Y_{2j}^* \sin(\delta_{2j} - \theta_{2j}) \tag{14}$$

And so on

$$\frac{dQ_n}{dV_n} = \sum_{j=1}^{n} V_j Y_{nj}^* \sin(\delta_{nj} - \theta_{nj}) \tag{15}$$

$$\frac{dQ_i}{dV_i} \propto \left(1 \Big/ \begin{matrix} \textit{Amount of load to be shed} \\ \textit{from each bus} \end{matrix} \right)$$

The above equation gives a fractional value of the voltage sensitivity for each bus. Now there is a direct relation between the amount load to be shed and the dV/dQ value at each bus.

$$\frac{dV_i}{dQ_i} \propto \left(\begin{matrix} \textit{Amount of load to be shed} \\ \textit{from each bus} \end{matrix} \right)$$

Hence closer a bus is to the knee point lower higher will be the dV/dQ value. Now, the summation of the dV/dQ values of all the buses is,

$$\sum_{i=1}^{n} \frac{dV_i}{dQ_i} = \frac{dV_1}{dQ_1} + \frac{dV_2}{dQ_2} + \cdots\cdots\cdots \frac{dV_n}{dQ_n} \tag{16}$$

The above equation gives the summation of the dV/dQ values at all the load buses. The load shed at each bus is a fraction of the total load required to be shed to maintain the power balance. This fraction of load at each bus is proportional to the fraction of the dV/dQ value at each bus with respect to the sum total calculated above. This is represented as

$$\frac{\frac{dV_i}{dQ_i}}{\frac{dV_1}{dQ_1} + \frac{dV_2}{dQ_2} + \cdots\cdots \frac{dV_n}{dQ_n}} \textit{ for each bus i.} \tag{17}$$

This is the fraction of the total voltage sensitivities. Thus closer the bus ‘i’ is to the knee point of the Q-V curve higher will the value of the above fraction be. Hence when this fraction is multiplied by the total amount of load to be shed, the load to be shed from each bus is obtained based on how close that bus is to the knee point. Thus more load is shed from a bus at which is desirable since this bus is critical from the voltage stability point of view. Thus the empirical formula to be tested out is

$$S_i = \frac{\left(\frac{dV_i}{dQ_i}\right)}{\sum_{i=1}^{n}\left(\frac{dV_i}{dQ_i}\right)} P_{diff} \tag{18}$$

At any frequency state between nominal and f_{TH} , the system is supposed to be self-stable, without any relay activation, through its stored energy and or spinning reserve. However, stored energy and spinning reserve are very much system dependent. Therefore, the more accurate value of f_{TH} may be determined through experience and simulations.

The threshold value of ROCOF, , is determined using a reduced model for a reheat unit. Considering constant system inertia, H, the methodology arrived at a solution that if 30% of the system real power is disturbed the system leads to exceeding the threshold value of ROCOF. Although in a small system H does not remain constant when multiple synchronous machines are disconnected from the system , however, this can be an approach of determining m_0.

The proposed technique prefers to determine m_0 heuristically from a series of simulation results and it considers m_0 as the lowest value of ROCOF for which the system can not be returned to the targeted steady state frequency range using traditional load shedding approach. The threshold value, m_i, corresponding to the th island is also the lowest value of ROCOF at which state the th disintegrated part of the power system cannot be returned to steady state condition, after islanding, with the traditional load shedding scheme.

The technique proposes in Section II-A that if traditional and ROCOF based load shedding approaches fail to bring a system into a steady state condition from an abnormal state, islanding is the last resort to rescue the system. Step 2 of this subsection also presents that if ROCOF is very high, islanding should be the first step instead of following the traditional and ROCOF based load shedding approaches. The threshold value,M, for such a case is determined heuristically, based on experience and simulation results.

C. Determination of Magnitude of Load Shedding and Time Delays

The magnitudes of load shedding of different steps of traditional scheme are not the same, and each step is implemented with certain time delay. The time delay corresponding to a step may be different from that of another step. The magnitude of load shedding of ROCOF based scheme is also different from that of the traditional one. Several load shedding solutions are available worldwide[1].

D .Formation of Island:

It is widely reported in the literature that islanding is an approach of preventing blackout in an extreme abnormality. But the question is what are the buses where the network should be disconnected to form an island. The formation of islands is not unique. Graph partitioning, minimal cutset enumeration, and generator grouping are the major approaches of islanding[8]. The essence of these approaches is to find the weak link/links among different zones of a power system. However, if the system is radial in nature, it is easier to identify the bus/buses where the system can be disintegrated by carefully inspecting the mismatches between loads and generations of different zones.

E. Procedure of Determining Settings of Different Types of Relays:

The activation frequency/frequencies with appropriate time delays of FS relays, i.e., relay settings, are evaluated. For the evaluation of these relay settings, all probable events, like different types of faults, withdrawal of different amount of generations, and additions of different amount of loads, are simulated. Due to the occurrence of each event, the system frequency is monitored. Then the falling frequency should be stabilized within the range of target frequency through appropriate load shedding[8]. The appropriate amount of load shedding may be obtained from different trials of shedding loads of different amount at different locations. That is, at what frequency level and locations of load are more effective in terms of system stability should be determined heuristically through trials. It should be noted that the target range of frequency, acceptable frequency range of normal operation, should be pre-defined from the experience of load dispatch center (LDC).

III. Comparison Between Propsed And Existing Method

Since olden days many methods are in practice to protect the power system from blackouts. One of the best method among them is traditional load shedding scheme[1][7]. In this scheme during an abnormal condition load shedding is done using the data provided through an emergency system in which back up is provided by means of virtual battery to compensate the over voltage during a fault .In this method the voltage variation was high than the existing method.

In the present proposed technique along with traditional load shedding scheme semi adaptive scheme is used. Through this method the voltage variation is lessened to maximum extent. In addition to both these methods disintegration method is also used. Due to this disintegration, system can be brought back to stable at more faster rate. As a proof the comparision between the outputs of both the methods the following results are displayed.

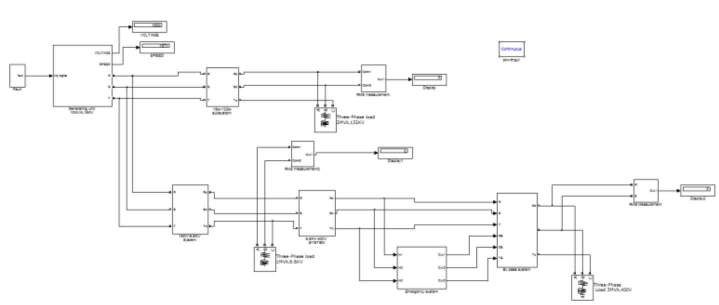

Fig. 2 Simulation diagram of Existing model

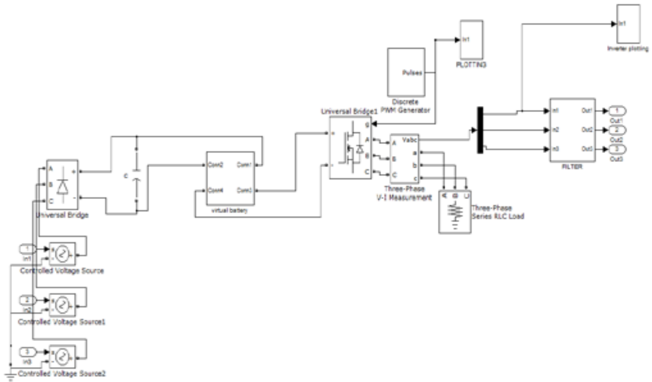

Fig. 3 Simulation diagram of emergency system

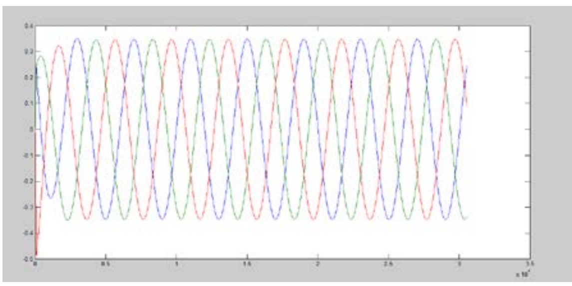

Fig. 4 Output voltage of synchronous generator in proposed technique

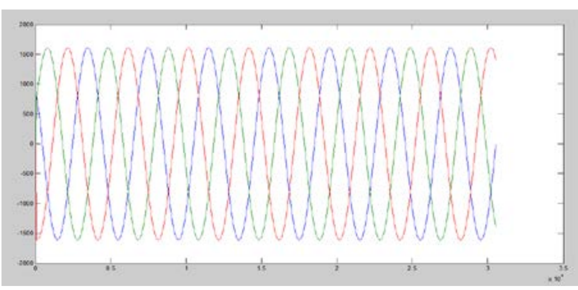

Fig. 5 Output voltage of emergency system in existing method

From Fig 4,Fig 5 it is clear that the proposed model is more efficient and system can be brought back to stable condition at faster rate in-order to prevent blackout.

IV. Conclusion

Abnormal condition in a power system created through fault or sudden load addition/withdrawn or forced capacity outages or all at a time generates a huge loss to the utility as well as to the consumers. The loss reaches to an extreme if the abnormal condition leads to a system blackout. Hence in this paper different simulation programs were developed for both traditional load shedding model and existing model (which was developed using battery backup).. From the figures it is clear that the voltage drop is more in existing model. This paper presents a technique in which an auto load shedding and islanding scheme can be developed for a system to bring it to a stable operating state during abnormal condition. It requires traditional and/or ROCOF based load shedding schemes to bring a system into a stable state from an abnormal state. However, in an extreme condition, the grid is disintegrated forming islands and brought the individual island into stable condition

In real time work technique developed will be used as a software which will be dumped into a micro-processor through which a specific relay will be operated to protect the system. In present work the technique is applied to three different sets of data to activate all the three schemes.

As a future study instead of shedding the load, abnormal conditions can be balanced by providing a backup to the system with the help of renewable energy sources.

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