US 20120041612A1

(19) **United States**

(12) **Patent Application Publication**

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(10) **Pub. No.: US 2012/0041612 A1**

(43) **Pub. Date: Feb. 16, 2012**

(54) **EMERGENCY FREQUENCY LOAD SHEDDING SCHEME**

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(21) Appl. No.: **13/282,032**

(22) Filed: **Oct. 26, 2011**

Related U.S. Application Data

(62) Division of application No. 12/131,986, filed on Jun. 3, 2008.

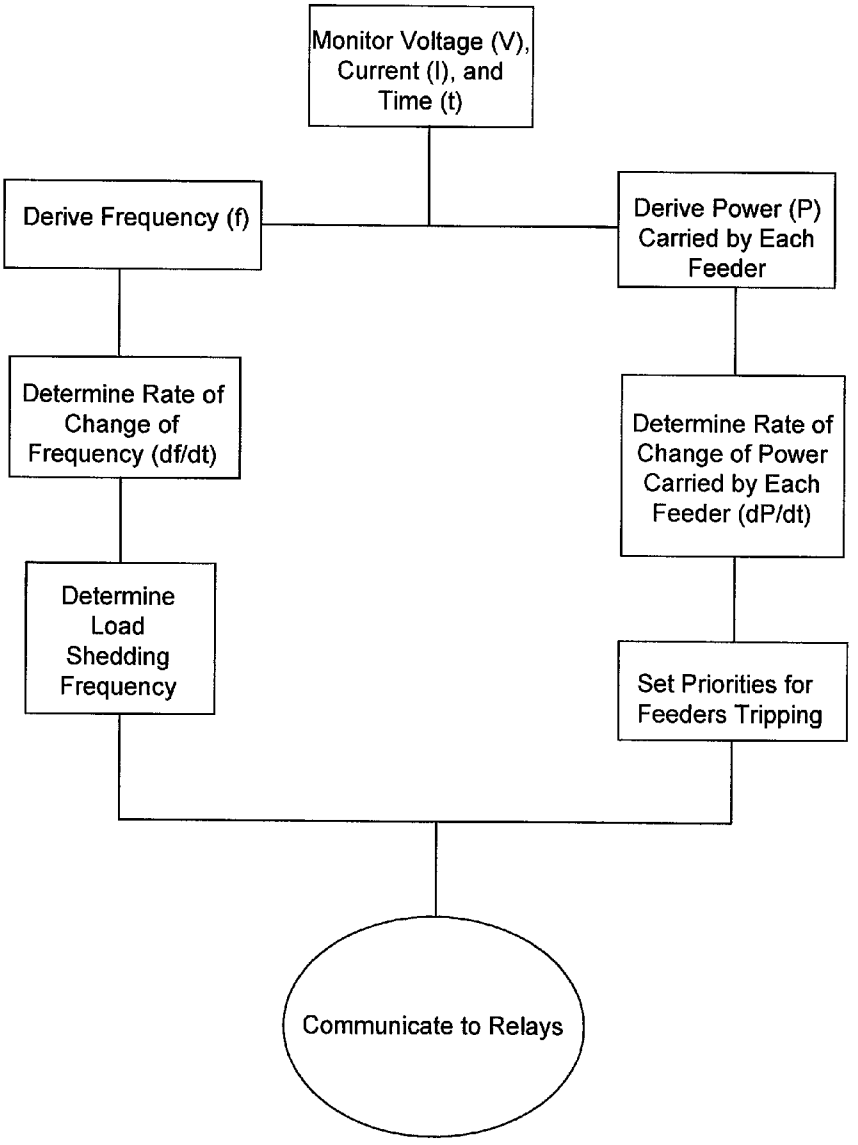
Publication Classification

(51) **Int. Cl.**
G06F 1/28 (2006.01)

(52) **U.S. Cl.** **700/292**

(57) **ABSTRACT**

A load shedding system and method for controlling imbalances in a power system includes a signal generator adapted to generate a signal representative of a local system, and a modifying circuit adapted to adjust set frequencies. The system also includes a processing circuit adapted to process data received from the signal generator and modifying circuit and set load shedding priorities for the local system based on the processed data.



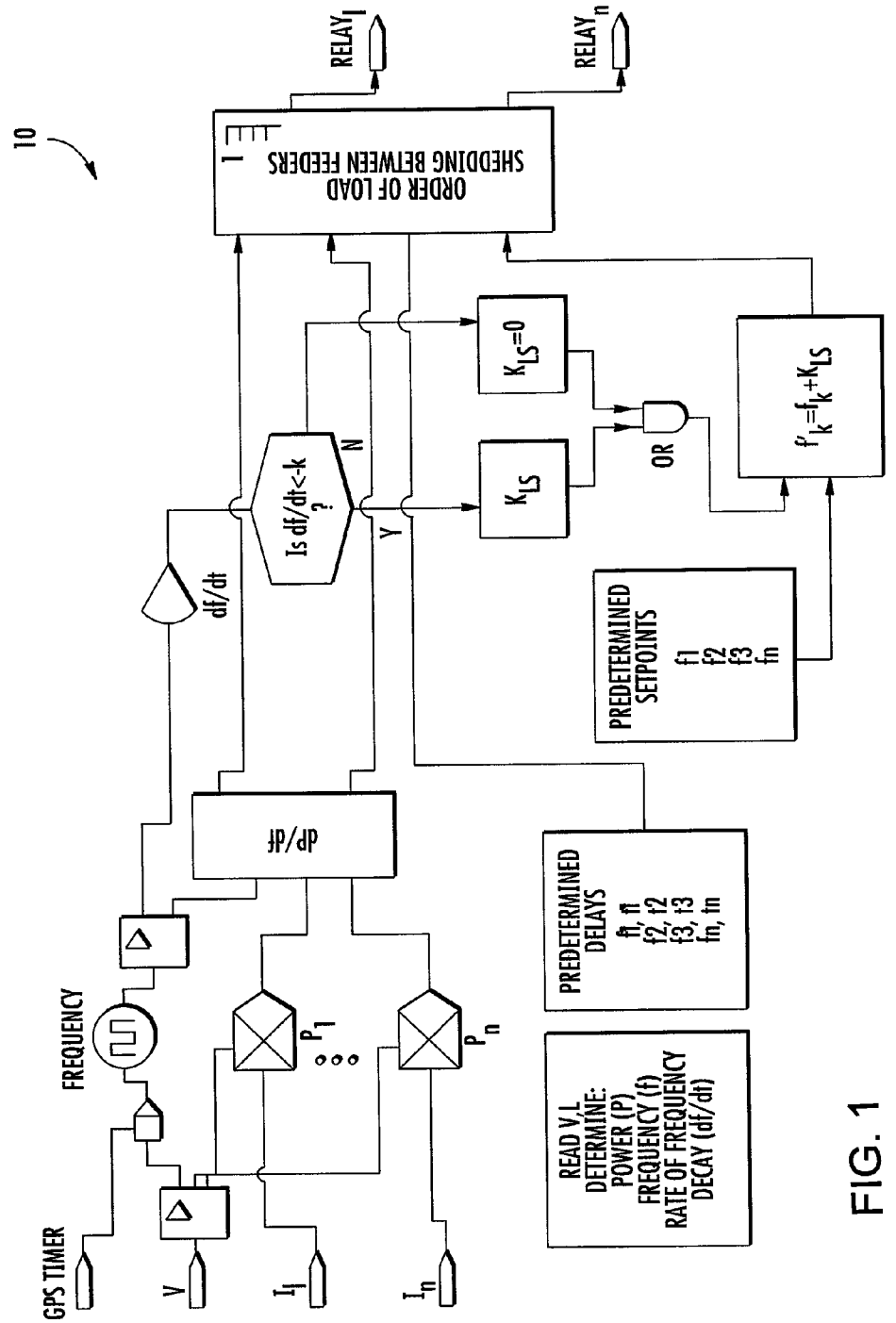

10
RELAY 1
RELAY n
ORDER OF LOAD SHEDDING BETWEEN FEEDERS
$K_{LS}=0$
K_{LS}
OR
$f'_k=f_k+K_{LS}$
Is df/dt<-k ?
N
Y
df/dt
PREDETERMINED SETPOINTS
f1
f2
f3
fn
dP/df
PREDETERMINED DELAYS
ft, f1
f2, t2
f3, t3
fn, tn
READ V,I, DETERMINE:
POWER (P)
FREQUENCY (f)
RATE OF FREQUENCY DECAY (df/dt)
FREQUENCY
P_1
P_n
GPS TIMER
V
I_1
I_n

FIG. 1

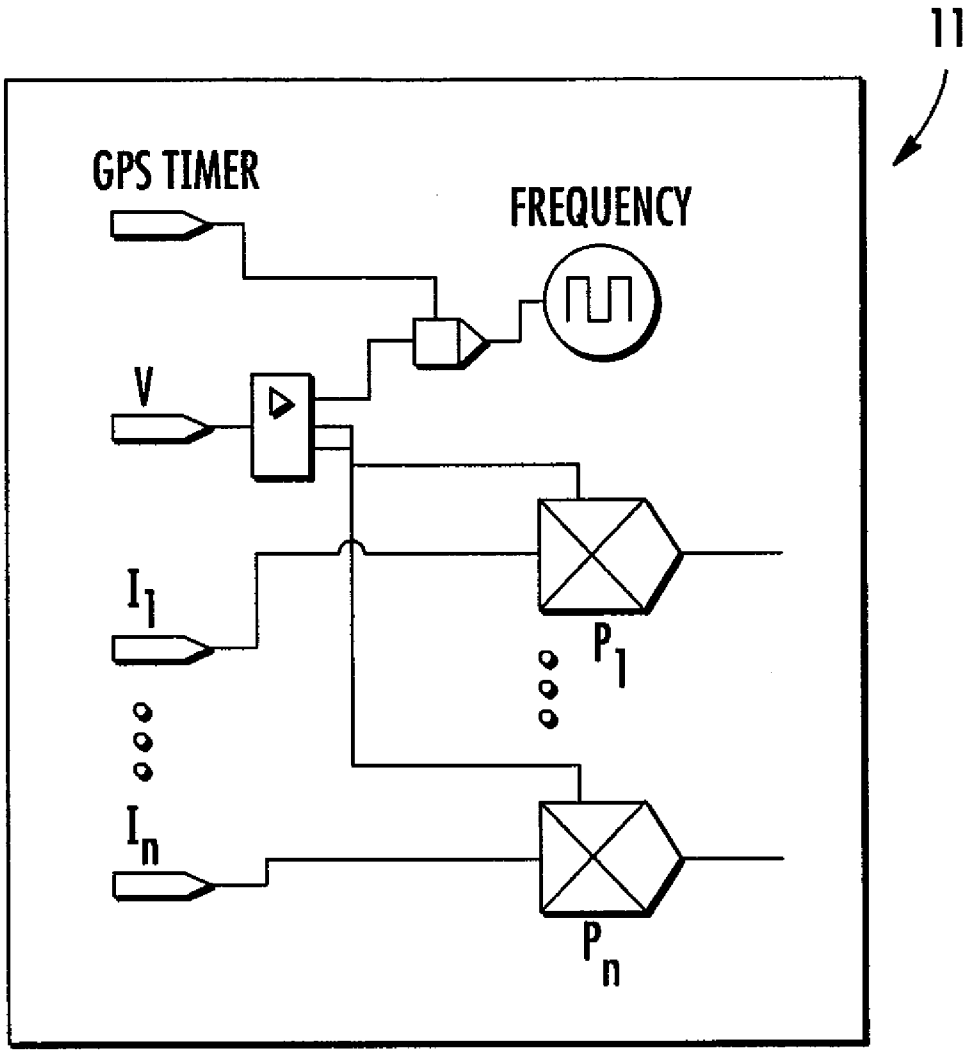


FIG. 2

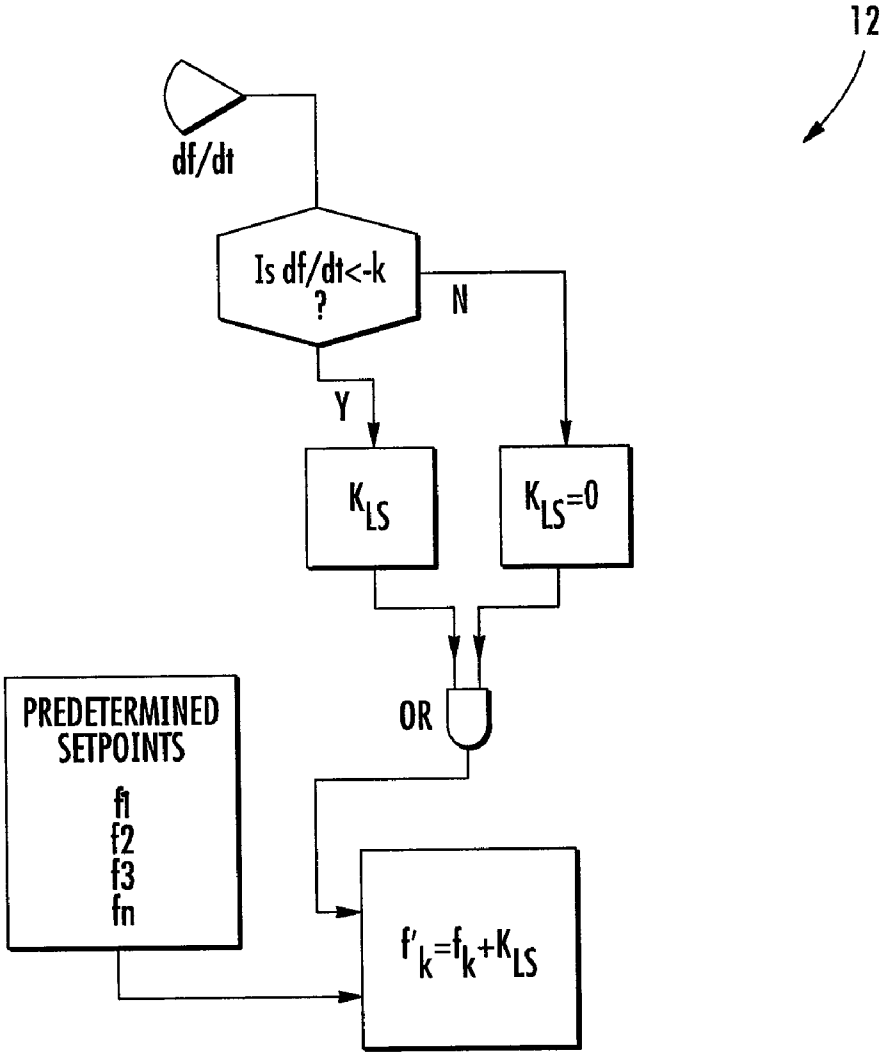

12
df/dt
Is df/dt<-k ?
N
Y
K_{LS}
K_{LS}=0
OR
PREDETERMINED SETPOINTS
f1
f2
f3
fn
$f'_k=f_k+K_{LS}$

FIG. 3

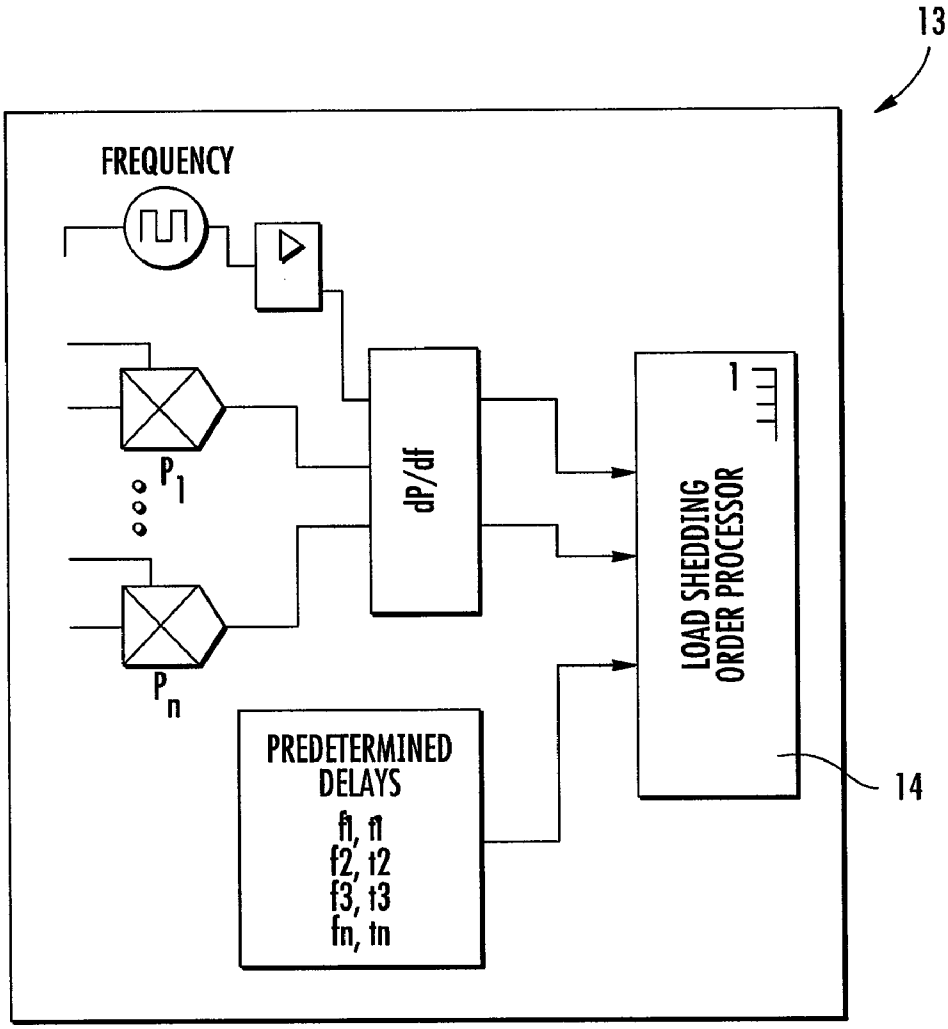

13
FREQUENCY
P1
Pn
dP/df
1
LOAD SHEDDING ORDER PROCESSOR
14
PREDETERMINED DELAYS
f1, t1
f2, t2
f3, t3
fn, tn

FIG. 4

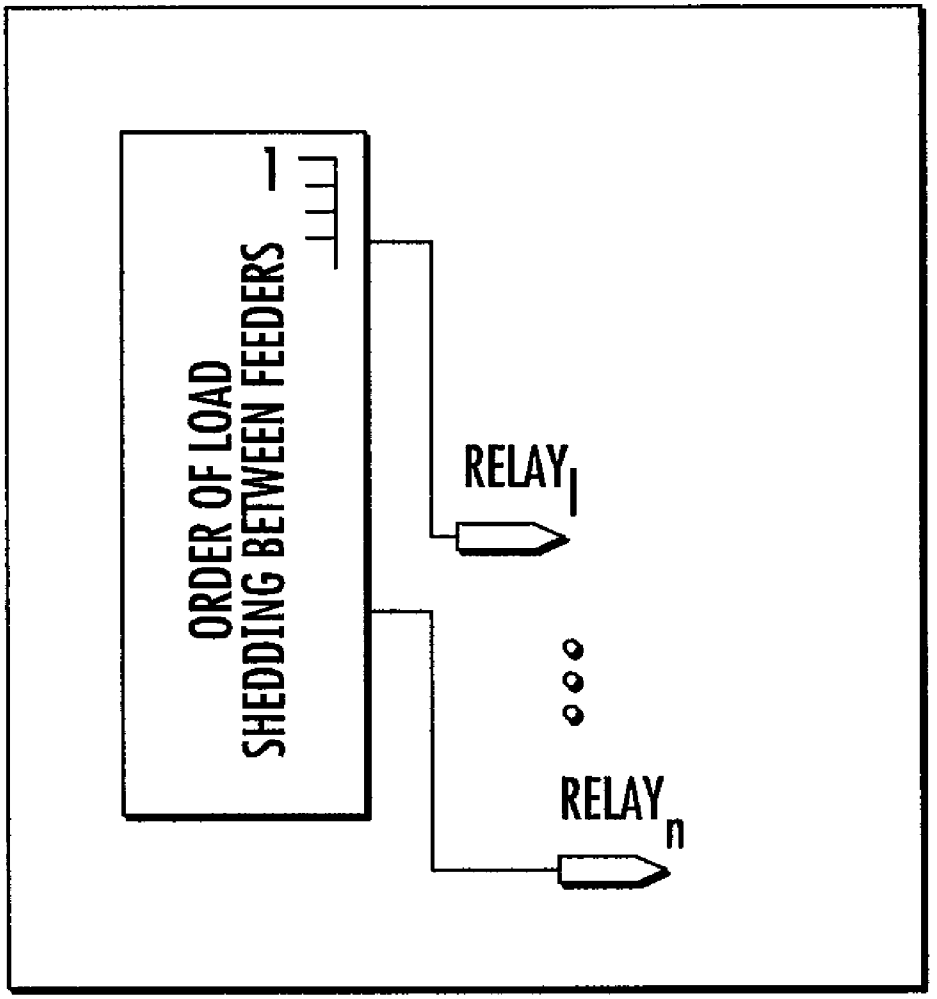


FIG. 5

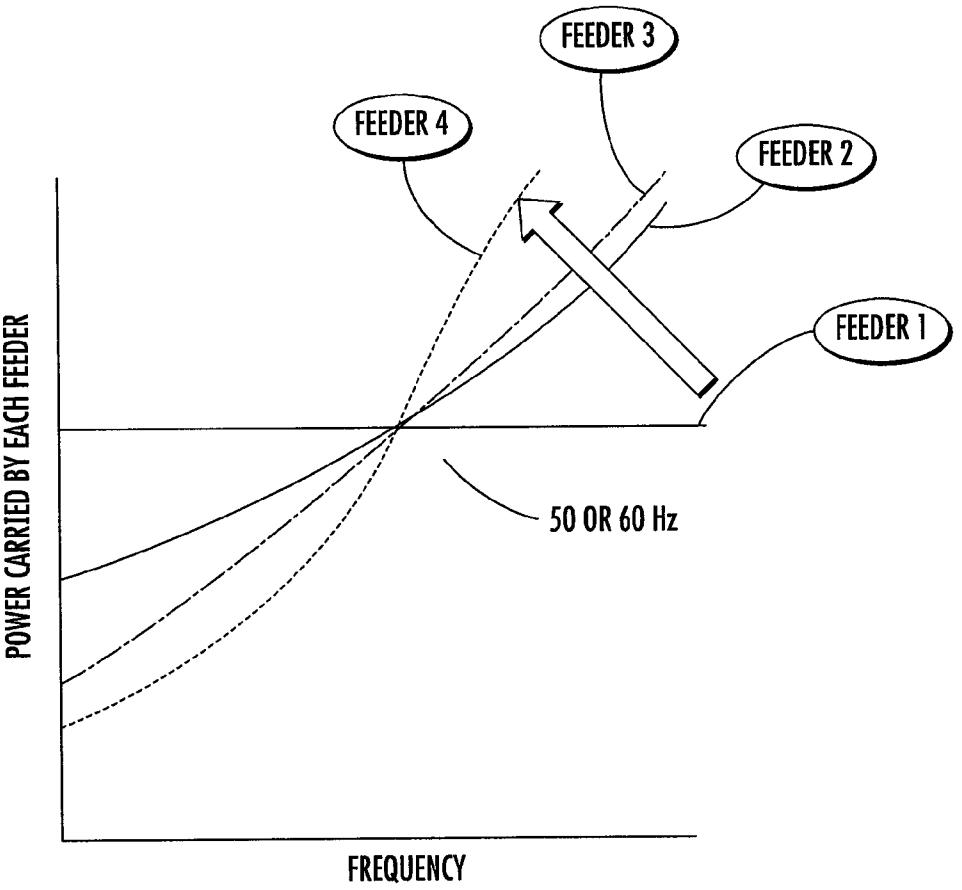

FEEDER 3
FEEDER 4
FEEDER 2
FEEDER 1
50 OR 60 Hz
POWER CARRIED BY EACH FEEDER
FREQUENCY

FIG. 6

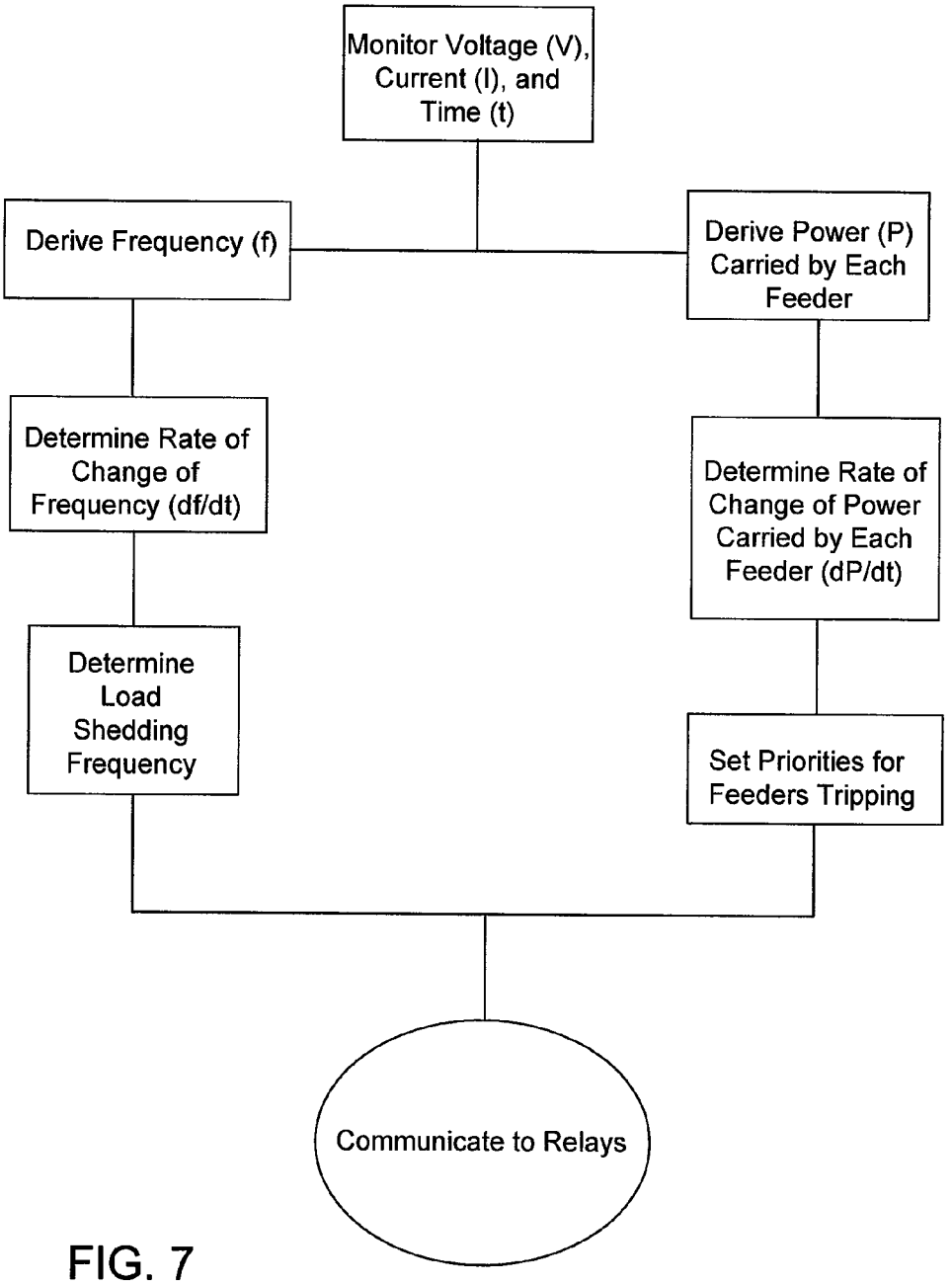

Monitor Voltage (V), Current (I), and Time (t)
Derive Frequency (f)
Derive Power (P) Carried by Each Feeder
Determine Rate of Change of Frequency (df/dt)
Determine Rate of Change of Power Carried by Each Feeder (dP/dt)
Determine Load Shedding Frequency
Set Priorities for Feeders Tripping
Communicate to Relays

FIG. 7

EMERGENCY FREQUENCY LOAD SHEDDING SCHEME

[0001] This application is a divisional application of U.S. patent application Ser. No. 12/131,986, filed Jun. 3, 2008, which is currently pending.

BACKGROUND OF THE INVENTION

[0002] The present invention relates generally to a system and method for controlling imbalances between load and supply in power systems, and more particularly to a load shedding system and method for controlling imbalances in a power system.

[0003] In power systems of today, it is essential that a balance between the amount of power being used ("load") and the amount of power being supplied ("supply") be maintained to provide a secure and reliable power system, thereby preventing blackouts and power interruptions. Every imbalance between the supply and load causes a deviation of the frequency. More importantly, if the load exceeds the supply and the deficit is not counteracted, the deficit in supply can lead to system interruptions and even blackouts.

[0004] One way to control these imbalances is to use load shedding. Load shedding (i.e., opening a circuit breaker to reduce the load) has been used to mitigate imbalances between supply and load since the infancy of power systems, and has basically remained unchanged over the last 100 years. During the same period, the logic used to shed the load has also only changed slightly. Unfortunately, the power systems, expectations of the users, and their loads have changed drastically, thereby necessitating better ways to handle these imbalances.

[0005] Currently, there are basically two kinds of under frequency load shedding schemes: the first is based on predetermined frequencies encountered during a frequency decline, and the second is based on the rate of decline of the frequency (i.e., first derivative of frequency with respect to time). Both schemes use different time delays (from zero delay to several seconds, in some cases).

[0006] The first scheme drops the load based on predefined frequencies, f**1**, f**2**, f**3**, . . . fn in the hope that the dropped load would be enough to reverse the frequency decline by narrowing the gap between the supply and the connected load. The predefined set points are based on previous studies, and they do not consider the actual state of the system when the disturbance occurs or any dynamic system conditions ensuing from the disturbance. Though this scheme is relatively good when there is a smaller disturbance coupled with a long time to respond, it is unable to differentiate between some "normal" system oscillations and actual system disturbances. Hence, it may not shed enough load to arrest a frequency decline associated with real disturbances. This could cause the disturbance to cascade and result in the system actually collapsing because the appropriate action (shed enough load) was not taken at the right time.

[0007] The second scheme for shedding load is based on the rate of change (first derivative) of the frequency decline (combined often with predefined frequencies). This scheme solves some of the concerns with the first scheme above by providing a means for a faster response to disturbances and a better method for differentiating disturbances from "normal" system oscillations. The rate of change of the frequency (df/dt) is used at some or all of the predefined frequencies.

[0008] Unfortunately, the last blackouts, including the 2003 North East Blackout, have shown that the above existing load shedding schemes are not sufficient to arrest frequency declines and can not save power systems from large disturbances. Accordingly, there is a need for a load shedding scheme that can sufficiently arrest frequency declines that result from large disturbances.

BRIEF SUMMARY OF THE INVENTION

[0009] These and other shortcomings of the prior art are addressed by the present invention, which provides an emergency frequency load shedding sheme that preempts a frequency decline by shedding load based on the severity of a disturbance.

[0010] According to one aspect of the present invention, a load shedding system includes a signal generator adapted to generate a signal representative of a local system; a modifying circuit adapted to adjust set frequencies; and a processing circuit adapted to process data received from the signal generator and modifying circuit and set load shedding priorities for the local system based on the processed data.

[0011] According to one aspect of the present invention, a method of pre-empting a frequency decline includes the steps of continuously monitoring voltage or current of a local system over a set time interval; estimating a rate of change of frequency with time from voltage and current measurements taken during the time interval; and using the rate of change of frequency with time to determine a frequency load shedding point.

[0012] According to one aspect of the present invention, a method of pre-empting a frequency decline includes the steps of continuously monitoring voltage and current of a feeder; estimating a rate of change of frequency with time from voltage and current measurements taken during a set time interval; estimating a rate of change of power with frequency; using the rate of change of frequency to determine a frequency load shedding point; and using the rate of change of power with frequency to set load shedding priorities.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The subject matter that is regarded as the invention may be best understood by reference to the following description taken in conjunction with the accompanying drawing figures in which:

[0014] FIG. **1** shows a load shedding system according to an embodiment of the invention;

[0015] FIG. **2** shows input circuitry of the system of FIG. **1**;

[0016] FIG. **3** shows a modifying circuit of the system of FIG. **1**;

[0017] FIG. **4** shows a logic circuit of the system of FIG. **1**;

[0018] FIG. **5** shows an individual relay of the system of FIG. **1**;

[0019] FIG. **6** shows how a sample of load frequency dependency for a feeder would react using the system of FIG. **1**; and

[0020] FIG. **7** shows a top level process for preempting a frequency decline using the system of FIG. **1**.

DETAILED DESCRIPTION OF THE INVENTION

[0021] Referring to the drawings, an exemplary emergency frequency load shedding scheme or system according to the present invention is illustrated in FIG. **1** and shown generally at reference numeral **10**. The system **10** is an adaptive emer-

gency load shedding system which can differentiate between disturbances and normal frequency oscillations. Unlike the prior art, the system may preempt a frequency decline by shedding load based on the severity of a disturbance. This allows the system to shed a load earlier than what the predetermined frequencies dictate.

[0022] Referring to FIG. **2**, the system **10** uses a signal generator **11** to provide a localized reading of a local power system frequency and power (P) carried by different feeders. Further, the signal generator **11** generates a signal equal to the frequency of the local system frequency and the power carried by the different feeders to which the system **10** acts on.

[0023] As shown in FIG. **3**, a modifying circuit **12** is used to adjust predefined set frequencies (f**1**, f**2**, . . . fn) based on the severity of a disturbance. As illustrated, the circuit **12** uses the instantaneous rate of frequency declines ("df/dt") to change the next trip frequency. For example, if df/dt is negative and the magnitude is larger than a user definable constant ("k"), which can be either determined or applied on a local basis or system wide, then the next pre-defined tripping frequency will be increased by a load shedding constant ("K_{LS}"), i.e., the load shedding will take place at a slightly higher frequency than the original corresponding set point. K_{LS} may be based on engineering judgment or on the results of studies or simulations of the system to which the system **10** is applied, but may be in the range of 0.1 to 0.3 Hz. It is expected that different power systems will have slightly different k's. For example, for large systems which are spread out over large geographic areas or where generating plants are concentrated in a certain area, applying slightly different K's at different locations could further enhance the system due to further differentiation of needed responses, and the ability to tailor the response of the grid more closely to what is needed to resolve the mismatch between generation and load.

[0024] As shown, if the rate of frequency, df/dt is greater than or equal to −k, then K_{LS} is set to zero and, hence, the load shedding will take place at the predetermined scheduled frequencies without any correction applied to them. However, if df/dt is smaller than −k (i.e., more negative), then K_{LS}, will be non zero and the load shedding will take place at an earlier value of frequency than the predetermined scheduled frequency.

[0025] Referring to FIGS. **4** and **5**, a processing circuit **13** processes data received from the signal generator **11** and the modifying circuit **12** and compares the data to predetermined frequencies (f_1, t_1 . . . f_n, t_n). It also calculates the rate of change of power with frequency ("dP_f/d_f") generated by the signal generator **11**. Once the data is analyzed by a load shedding processor **14**, priorities are set for feeder tripping based on their frequency characteristics. Thus, processor **14** prioritizes the order of shedding between feeders in real time based on the type of load they carry. Dropping loads with less frequency dependency is more beneficial than dropping loads with more frequency dependence.

[0026] As shown in FIG. **6**, feeders having different load characteristics are tripped in different orders. As shown, the priority of tripping will be from the less frequency dependent (flatter characteristics like feeder **1**) to the most frequency dependent (as feeder **4**). Tripping the less frequency dependent first is more advantageous than tripping the more frequency dependent load because the power carried is independent of the frequency drop and it establishes a balance between load and supply quicker.

[0027] In use, FIG. **7**, voltage ("V") and current ("I") measurements, and time, ("t") are continuously monitored by a control system, computer, processor, or other suitable system or device. From the raw values of V and I, a frequency ("f") signal is derived. Time is established with a GPS device, while f can be derived based on zero crossing of the voltage signal, or other suitable method. From the measured V and I, magnitudes of the real power (P) carried by the different feeders are calculated.

[0028] Monitoring is done on a continuous basis; hence, the change in frequencies forms two measurements separated by a sampling interval; thus, yielding an estimate of the rate of change of frequency with time. This is also known as the first derivative of frequency with time (df/dt). Similarly, the rate of change of P with respect to frequency, or the first derivative of power with frequency (dP/df) may be derived from consecutive P and f measurements.

[0029] The value of df/dt provides an indication of the severity of the disturbance. The more negative in magnitude df/dt is, the more severe the disturbances. A positive df/dt indicates that the frequency decay is recovering. In the case of dP/df, a zero (0) value implies that the load is independent of frequency. A less negative value implies less dependence of frequency. A positive dP/df would indicate an increase of the load with the frequency; however, it is unlikely that this would occur.

[0030] From the df/dt values, the system **10** determines a new frequency load shedding point. This is based on the next predetermined (set point) load shedding value. The current df/dt alters the value at which the next load shedding event will take place, with more severe disturbances represented when df/dt is more negative than K_{LS} and resulting in shedding load at higher frequencies. When df/dt is less negative than K_{LS}, then load shedding will take place at the predetermined load shedding frequency.

[0031] Similarly, dP/df is used to set the priority of the shedding of the different feeders based on the frequency dependency of the load they carry. This is determined by how negative the rate of change of power with frequency (dP/df) is for each feeder, with smaller values of dP/df having higher priority. This priority is then communicated as trip signals to different actual relays, and then to associated breakers.

[0032] The foregoing has described an emergency frequency load shedding scheme. While specific embodiments of the present invention have been described, it will be apparent to those skilled in the art that various modifications thereto can be made without departing from the spirit and scope of the invention. Accordingly, the foregoing description of the preferred embodiment of the invention and the best mode for practicing the invention are provided for the purpose of illustration only and not for the purpose of limitation.

What is claimed is:

1. A method of pre-empting a frequency decline, comprising the steps of:

(a) continuously monitoring voltage of a local system over a set time interval;

(b) estimating a rate of change of frequency with time from voltage measurements taken during the time interval; and

(c) using the rate of change of frequency with time to determine a frequency load shedding point.

2. The method according to claim **1**, further including the step of deriving a frequency signal indicative of the local system.

3. The method according to claim **1**, further including the step of determining a magnitude of power carried by the local system.

4. The method according to claim **1**, further including the step of determining a change of power with frequency.

5. The method according to claim **1**, further including the step of setting load shedding priorities for the local system.

6. A method of pre-empting a frequency decline, comprising the steps of:

(a) continuously monitoring voltage and current of a feeder;

(b) estimating a rate of change of frequency with time from voltage and current measurements taken during a set time interval;

(c) estimating a rate of change of power with frequency;

(d) using the rate of change of frequency to determine a frequency load shedding point; and

(e) using the rate of change of power with frequency to set load shedding priorities.

7. The method according to claim **6**, further including the step of deriving a frequency signal indicative of the local system.

8. The method according to claim **6**, further including the step of determining a magnitude of power carried by the local system.

9. The method according to claim **6**, further including the step of comparing the rate of change of frequency with time to a load shedding constant.

10. The method according to claim **9**, wherein if the rate of change of frequency with time is more negative than the load shedding constant, load shedding occurs at higher frequencies.

11. The method according to claim **9**, wherein if the rate of change of frequency with time is less negative than the load shedding constant, load shedding occurs at predetermined frequencies.

12. The method according to claim **6**, further including the step of communicating load shedding priorities to relays and breakers.

13. The method according to claim **6**, wherein the more negative the rate of change of power with frequency is the higher the load shedding priority is for a feeder.

* * * * *