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WATER SUPPLY SYSTEM

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BACKGROUND OF THE INVENTION

The present invention relates to a water supply system which has a pump control function and includes variable speed pumps driven by inverter
5 devices having protection means for protecting themselves and more particularly, to a water supply system which, even when the operation of one of the inverter devices is stopped by its own protection means, can continue water supply.

10 A prior art water supply system using variable speed pumps is arranged so that a control circuit having a microcomputer built therein for commanding the operation of inverter devices is separately provided, a fluctuation in the amount of
15 demand water causes a frequency command to be issued to the inverter devices, whereby the operational speed of motors driving pumps is changed to keep a constant pressure relationship (for example, constant discharge water pressure or constant end-user water pressure) at
20 discharge sides of the pumps to continue water supply. Examples of this type of system are disclosed, e.g., in JP-B-6-52079 and JP-B-6-52080.

Inverter devices used in this type of water supply system have various sorts of protection circuits
25 built therein for protecting themselves. Details of

protection systems of such inverter devices are described, e.g., in JP-A-57-6576, JP-A-58-224575, JP-A-59-185170, JP-A-60-84972 and JP-A-61-224876.

In this way, since the inverter devices in
5 the water supply system have various sorts of protection circuits built therein for protecting their inverter devices, the inverter devices are stopped due to various causes (such as momentary power failure, excessive load, temperature rise, noise, etc.).
10 Further, a water supply suspension during stoppage of the inverter device involves a big problem. For the purpose of avoiding such a situation, in this case, a motor for driving the pump is usually switched from its inverter operational mode to its rated or fixed speed
15 operational mode based on a commercial power source to prevent the water supply suspension.

SUMMARY OF THE INVENTION

In such a prior art water supply system as mentioned above, however, it has been impossible, when
20 a control circuit having a microcomputer built therein becomes faulty, to avoid water supply suspension so long as the control circuit is not of a perfect dual system type.

Further, when the inverter device is stopped
25 by some cause and the rated or fixed speed operation of the pump based on the commercial power source is continued, this causes a discharge water pressure to be

varied in response to a variation in the amount of demand water. Furthermore, since the pump is driven at its full speed even under a light load, the pump running power cost becomes undesirably high.

5 The prior art water supply system also has had a problem that, in case of stoppage of the inverter device, it is required to quickly locate its stoppage cause and to restart the inverter device, which undesirably leads to the fact that, as soon as an alarm
10 is issued from the inverter device, a maintenance worker must receive an emergency call and be called for its repair.

 Therefore, it is an object of the present invention to provide such an improved water supply
15 system that can completely avoid or minimize the stopped state of the built-in inverter device and can maintain continuous water supply.

 In accordance with an aspect of the present invention, this object is attained by providing a water
20 supply system which comprises sensor input means for inputting information signals on water supply from a pressure sensor and a flow sensor mounted to a tap water distribution pipe, a plurality of inverter devices having protection means for protecting them-
25 selves for generating variable frequency AC power according to a preprogrammed drive schedule, a plurality of motors connected to the inverter devices for being driven with a variable speed when receiving power

from the inverter devices, and a plurality of variable speed pumps connected to the motors for supplying water to the tap water distribution pipe, and wherein each of the inverter devices includes means for monitoring the
5 faulty state of the other inverter devices and, when an inverter device is stopped by its protection means, for outputting a start command to the faulty inverter device (i.e. restart means) or for operating a normal inverter device in place of the faulty inverter device.

10 The restart means of the pump controller are arranged so that, when one inverter device is stopped by its own protection means, the restart means of a different inverter device issues a start command to the stopped inverter device. Accordingly, when the protec-
15 tion cause of the stopped inverter device is already removed at the time of giving the restart command to the stopped inverter device, the stopped inverter device is restarted, whereby there can be reduced a possibility that the inverter devices are completely
20 stopped.

 Since the pump controller eliminates the need for provision of a control circuit having a microcomputer built therein and requires only two inverter devices, a water supply system of a perfect dual system
25 type can be realized with an increased reliability.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram for explaining an

entire arrangement of a water supply system in accordance with an embodiment of the present invention;

Fig. 2 is a circuit diagram of a controller in the water supply system of Fig. 2;

5 Fig. 3 shows details of terminals of an inverter device in the controller;

Fig. 4 is a block diagram for explaining the software operation of the inverter device;

10 Fig. 5 is a flowchart for explaining a basic part of the software operation of the block diagram of Fig. 4;

Fig. 6 is a flowchart for explaining the details of re-starting operation of an inverter device included in the basic operation of the software;

15 Figs. 7 is an example of use of interlock signals when two inverter devices are used to send and receive the interlock signals in the present invention;

Fig. 8 is an example of use of a single interlock signal when three or more inverter devices are employed in the present invention; and

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Fig. 9 is an example of memory allocation when three or more inverter devices are used to send and receive interlock signals in the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

25 An embodiment of the present invention will be detailed with reference to the accompanying drawings 1 to 9.

Fig. 1 is a block diagram for explaining an entire arrangement of a water supply system in accordance with an embodiment of the present invention, Fig. 2 is a circuit diagram of a controller in the water supply system of Fig. 2, Fig. 3 shows details of terminals of an inverter device in the controller, Fig. 4 is a block diagram for explaining the software operation of the inverter device, Fig. 5 is a flowchart for explaining a basic part of the software operation of the block diagram of Fig. 4, Fig. 6 is a flowchart for explaining the details of re-starting operation of the other inverter device included in the basic operation of the software, and Figs. 7 to 9 show other examples of interlock signal or signals which can be applied to three or more of the inverter devices.

Referring first to Fig. 1, a controller 1, which includes inverter devices 20, 21 and leak circuit breakers 40, 41, performs control over a water supply unit 2. The water supply unit 2 in turn includes motor-driven pumps 105, 106, pressure sensors 102, 112, flow switches 107, 117, an inflow-side stream-combination pipe 104, a discharge- or outflow-side stream-combination pipe 110, a pressure tank 111, pressure gauges 114, 115 and other various types of valves 100, 101, 103, 108, 109. With the arrangement, the water supply unit 2 functions to boost the water pressure of a tap water main pipe 116 to supply water to a water distribution pipe 118.

A main circuit power source 10 supplies 3-phase AC power to the controller 1. More specifically, the inverter devices 20 and 21 receives power from terminals R, S and T, and output variable frequency AC power to terminals U, V and W according to a pre-programmed drive schedule to perform variable-speed driving operation of the motor-driven pumps 105 and 106.

Detection signals detected by an outflow-side pressure sensor 112, the pressure sensor 102 and the flow switches 107 and 117 are applied to the inverter devices 20 and 21, which in turn, on the basis of the received detection signals, convert the received power to variable frequency AC power to carry out a constant water-discharge-pressure control or a constant end-user pressure control according to the preprogrammed drive schedule and supply it to the motor-driven pumps 105 and 106.

The motor-driven pumps 105 and 106 alternately carry out their automatic pumping operation. This causes the inverter devices 20 and 21 to mutually monitor the other inverter devices based on interlock signals 61 and 62 to control its own start and stop.

In Fig. 2, a noise filter NF60 and a zero-phase reactor ZCL50 attenuate electrical noise superimposed on a current supplied from the main circuit power source 10 to protect the inverter devices 20 and 21, and also prevent electrical noise caused by

harmonic currents generated by the inverter devices 20 and 21 from being fed back to the main circuit power source 10. Zero-phase reactors 51 and 52 suppress transient currents to be applied to the motor-driven pumps 105 and 106 from the inverter devices 20 and 21 to thereby reduce noise generated at the time of driving the motor-driven pumps 105 and 106.

The leak circuit breakers 40 and 41 detect a leak current for preventing users' electric shock, and are also used as power ON/OFF switches at the time of maintenance and security check of the motor-driven pumps 105 and 106 and inverter devices 20 and 21.

Digital operators 30 and 31 are provided as accessories for the inverter devices 20 and 21, which, when a pushbutton switch provided in their front lower part is operated, can put the inverter devices 20 and 21 in their initialization or test operation mode and can display the output frequency, load current or fault information on the inverter devices 20 and 21 on numeric indicators provided on its front upper part to know the working status of the system.

Shown in Fig. 3 are input/output terminals of the inverter devices 20 and 21, which will be explained in more detail in the following.

The interlock signals 61 and 62 are associated with an output signal terminal D02 for informing the other inverter device that the inverter device of interest was stopped by its own protection function

(self trip), an input terminal DI1 for input of a restart command signal (alternate command ENQ) from the other inverter device, an input terminal DI2 for input of a message telling that the other inverter device was stopped by its own protection function (the other party trip), and an output signal terminal DO1 for output of a restart command signal (alternate command ACK) to the other inverter device. Sensor input terminals AI1 and AI2 are analog input terminals for reception of signals from the pressure sensors 102 and 112. A signal FS issued from the flow switch 107 is applied as a bit signal to a terminal FW. Signals issued from digital operators 30 and 31 are connected to serial communication ports SD and RD. Also provided in the present embodiment are bit output terminals D03 to D05 for informing an external device of an abnormality detected by the inverter devices 20 and 21.

Fig. 4 is a block diagram for explaining the software-based operation of a microcomputer built in the inverter devices 20 and 21. In the figure, a normal operation block 401 stores therein a pump driving schedule, according to which the output frequency and drive/stop commands of the inverters are calculated on the basis of the data of the interlock signals and pressure sensor signals. The block 401 issues its calculation result to a LAD operation block 402. The block 402, on the basis of the calculated output frequency and drive/stop commands as well as the

characteristics of the inverters, generates a command indicative of a detailed output frequency and output voltage and sends the command to a PWM operation block 403. The block 403 outputs to a inverter main circuit 407 a signal PWM (pulse width control signal) for driving switching elements in the inverter main circuit 407 to cause the inverters to output variable frequency power based on the calculated output frequency and output voltage commands. An excessive current reference value as a detection level of an excessive load current of the inverters is sent from the normal operation block 401 to a trip operation block 404 to be stored therein. The trip operation block 404 always monitors the excessive current reference value and the inverter load current and, when detecting an excessive load current, generates trip information and issues it to a command processing block 405. Also applied to the normal operation block 401 is a voltage PN (a voltage between positive and negative levels in an intermediate DC voltage) of the inverter main circuit so that the block 401 detects an excessive or insufficient or short voltage and sends the detection signal to the trip operation block 404. The command processing block 405 . executes exception handling operations including abnormality operation (such as excessive current or excessive voltage or short voltage) from the inverter trip operation block 404, communication operation based on the key information of the digital operators 30 and

31, output of a display signal LED to the digital operators 30 and 31, and data read/write operation of a nonvolatile memory (EEPROM) 408. A EEPROM input/output operation block 406, on the basis of an EPROM write
5 command or a call request command received from the command processing block 405, directly accesses the nonvolatile memory 408 and executes transfer of those data which need to be stored even in case of a power
10 failure, such as basic parameters required for the driving schedule and fault history data, between the blocks 406 and 405.

An example of the normal operation block 401 is shown by a flowchart in Fig. 5. When power is supplied to the inverter devices 20 and 21, the normal
15 operation block 401 executes an initialization step 501, reads out from the nonvolatile memory 408 a discharge target pressure H_0 , lowest drive speed NS , highest drive speed N_f , speed change width ΔN , restart judgement time T and restart frequency m , as parameters
20 necessary for the pump drive control, and sets the parameters in a register for calculation of the inverter output frequency.

Then the normal operation block 401 executes a step 502 to apply signals from the pressure sensors
25 102 and 112 and flow switches 107 and 117 respectively to the sensor input terminals $AI1$, $AI2$ and FW .

Subsequently, the normal operation block 401 executes a step 503 to input an operational state of

the other inverter device (which will be referred to as the other party inverter device, hereinafter) in the controller 1 with use of the interlock signals 61 and 62 and also to output its own operational state to the other party inverter device.

The normal operation block 401 then executes a step 504 to examine the operational state of the other party inverter device. The normal operation block 401, when judging that the operational state of the other party is normal, proceeds to a next pump control step 505; whereas, when judging that the operational state is abnormal, the block 401 executes a step 510 to be detailed later in connection with Fig. 6 to execute the restarting operation of the other party inverter device, after which the step 401 proceeds to the next pump control step 505.

Next, the block 401 executes the pump control step 505 in which a current supply water pressure H is compared with the discharge target pressure H_0 . If $H > H_0$ then the system goes to steps 508 and 509 to perform rate increasing operation; whereas, if $H_0 > H$ then the system proceeds to steps 506 and 507 to perform rate decreasing operation. When $H = H_0$, no rate change is carried out.

The normal operation block 401 then returns to the execution of the step 502 to repetitively execute the subsequent same operation.

Fig. 6 shows a flowchart for explaining

details of the step 510 of restarting the other party inverter device included in the normal operation block 401, which will be detailed below.

When it is judged through the execution of the step 504 that the operational state of the other party inverter device is abnormal, the other party restarting step 510 is executed.

In the party restarting step 510, a restart frequency MAX_m of the inverter device is determined first in a step 601. The restart of the inverter device requires a discharge time for the control circuit of the same inverter, that is, a restart time of usually 3-5 seconds. During the restart time, even when the pump is stopped, the pressure tank 111 is provided in the present embodiment, so that the supply water pressure H is prevented from quickly dropping as long as the amount of supply water (demand water amount) is small, which provides a time margin sufficient to execute the restarting operation of the inverter device a plurality of times. Meanwhile, when the water supply amount becomes large with the less time margin, it becomes necessary to limit the restart frequency. The water supply amount can be detected directly by a flow sensor and thus the restart frequency MAX_m can be determined. However, since there is a predetermined relationship among a pump rotational speed N , a discharge flow amount Q and a discharge water pressure H , which is as a Q - H characteristic with the pump

rotational speed N as its parameter; the pump rotational speed N may be used in place of the supply water amount to determine the restart frequency MAX_m as in a step 7. That is, as shown in the step 7, an initial value m_0 of the restart frequency according to the water supply conditions is previously registered in the inverter device through the digital operator, so that the larger the pump rotational speed N at the time of a faulty of the inverter device is, i.e., the more the water supply amount at the time of the fault is, the smaller the value of the restart frequency MAX_m is set.

In a step 603, next, the system sends a restart command to the abnormal inverter device, waits for the restart processing time T (3 seconds in the present embodiment), and confirms that the inverter device was restarted in a step 604. If the inverter device was restarted in the step 604, then the system goes to a step 610 to record its abnormal history and returns to the normal operation. If not restarted, the system repeats the restarting operations of a loop formed by the steps 605, 609, 603 and 604.

When the restart frequency reaches MAX_m , the system executes a step 607 and, so long as the pump discharge pressure is higher than a lowest guarantee pressure H_3 , continues the restarting operation of the inverter device through a loop of the steps 607, 609, 602, 603, 604 and 605. In the step 607, even when the restart frequency exceeds MAX_m , the system tries to

send a restart command to the inverter device to avoid the abnormal condition of the inverter device for continuation of water supply, so long as the lowest guarantee pressure H3 can be secured.

5 In the step 607, when the discharge pressure becomes lower than the lowest guarantee pressure H3, the system executes a step 608. In the step 608, the system stops the inverter device in its abnormal condition and performs a processing to fixedly set an
10 alternate drive mode wherein the other normal inverter device is driven in place of the abnormal inverter device, and also issues a fault alarm.

 Through such repetitive operations as mentioned above, the normal operation block 401
15 executes the monitoring operation of the state of the other party inverter, the restarting operation at the time of an abnormality and the variable speed driving operation of the water supply pump concurrently.

 Although the restart frequency MAXm has been
20 determined from the pump rotational speed N in the step 7, the restart frequency may be roughly determined in such a manner that, taking into consideration the fact that a water supply amount handled by the pump in its daytime operation is generally more than that handled
25 by the pump in its nighttime operation, the restart frequency in the daytime operation is set to be smaller than that in the nighttime operation.

Turning now to Figs. 7 to 9, there are shown

other examples of the interlock signals 61 and 62 which are applicable to a system having three or more inverter devices.

In Fig. 7, a send port TXD of an inverter device 71 is coupled to a receive port RXD of an inverter device 72 via the interlock signal 62, and a send port TXD of the inverter device 72 is coupled to a receive port RXD of the inverter device 71 via the interlock signal 61, whereby the mutual monitoring of the driving operation as well as the transmission of drive commands (including the aforementioned restart command) can be realized in a 1:1 serial communication relationship. When the number of such inverter devices are increased, e.g., to 3 or 4, this requires that one inverter device communicate with the other inverter devices, which disadvantageously results in that the number of such send ports TXD and the number of such receive ports RXD must be increased to 2 or 3 and thus the manufacturing costs of the inverter devices and communication channels become uneconomically high.

In order to avoid such a disadvantage, an arrangement shown in Fig. 8 is such that inverter devices are connected in such a loop that their send and receive ports TXD and RXD are coupled via a single continuous interlock signal. In this case, when data of all the inverter devices having such a communication data format as shown in Fig. 8,(a) are carried on the above-mentioned loop for communication, each of the

inverter devices is only required to have a single send port TXD and a single receive port RXD for the purpose of communication with the all other inverter devices. In Fig. 8,(a), symbol "ST. No." at the head of each inverter data is uniquely given to each inverter device to uniquely specify one of the inverter devices with which the data is associated, by means of a number allocated to each inverter device in the illustrated example. The "ST. No." is followed by data "DATA" which is the body of data indicative of the monitored state of the driven operation and a drive command to be transmitted, which is further followed by data "CRC" for execution of error detection of communication data. Each of the inverter devices sends the data in its own send data buffer via its send port TXD, receives at its receive port RXD data from the all other inverter devices, and stores it in its own receive data buffer.

Shown in Fig. 9 is an example of memory layout or allocation in the aforementioned send and receive data buffers. In Fig. 9, each of inverter devices 1 to 4 has a send and receive buffer having a memory capacity of 1 kilobyte, in which 256 bytes of send area in each buffer is allocated so as not to be overlapped with each other among the buffers. Each inverter device always communicates with the other inverter devices, and sends the data in its own send area as the interlock signal according to its own driving condition to always monitor its receive areas

to cope with the switching of operation or an abnormality.

Though the above communication system is of a serial communication type, in the case of the embodiment of Fig. 9, when 1 kilobyte of data is transmitted at a standard serial communication rate of 19.5Kbps, its response rate is about 1 second, which is sufficiently fast for pump control.

As has been explained in the foregoing, in accordance with the present invention, there is provided a restarting means which, when one inverter device is stopped by its own protection function, restarts the faulty inverter device by the other inverter device, and the restarting operation is carried out by its own inverter device, whereby perfect dual control system can be realized, the inverter devices can be less frequently stopped, and the water supply system can be improved in its reliability.

Further, since the need for provision of an external controller can be eliminated, the number of parts necessary for the entire control system can be reduced and thus the costs can be effectively lowered.



WHAT IS CLAIMED IS:

1. A water supply system characterized by comprising:

a plurality of inverter devices having protection means for protecting themselves for generating variable frequency AC power according to a preprogrammed drive schedule;

a plurality of motors connected to said inverter devices for being driven with a variable speed when receiving power from said inverter devices; and

a plurality of variable speed pumps connected to said motors for supplying water to a tap water distribution pipe,

wherein each of said inverter devices includes fault monitoring means for monitoring operation of said protection means of the other inverter device and restart means for outputting a start command to the other inverter device which fault was detected by said fault monitoring means.

2. A water supply system as set forth in claim 1, characterized by further comprising water supply state detection means for detecting a water supply state of each of said pumps, and wherein said restart means determines a restart frequency of said inverter device according to the pump water supply state detected by said water supply state detection means and causes the other inverter device to restart the faulty inverter device.



3. A water supply system as set forth in claim 2, characterized in that said water supply state detection means for detecting the water supply state of the pump is a guarantee pressure detector for detecting that a discharge water pressure of the pump became smaller than a predetermined guarantee pressure, and said restart means repeats the restarting operation of the inverter device so long as said guarantee pressure detector detects that said discharge water pressure of the pump is higher than said predetermined guarantee pressure.

4. A water supply system as set forth in claim 2, characterized by further comprising memory means for storing therein values of restart frequencies of said inverter devices previously determined according to the water supply states of said pumps, and wherein said restart means selects one of the restart frequencies stored in said memory means according to the pump water supply state detected by said water supply state detection means and repeats the restarting operation by the number of times corresponding to said selected restart frequency or less.

5. A water supply system as set forth in claim 2, characterized in that said water supply state detection means for detecting the water supply state of the pump is means for detecting an increase or decrease in a water supply amount of said pump and, when said water supply amount increase/decrease detection means



detects the increase in the water supply amount of the pump, said restart means decreases the restart frequency of the inverter device.

6. A water supply system as set forth in claim 2, characterized in that said water supply state detection means for detecting the water supply state of the pump is pump speed detection means for detecting a driven speed of the pump, and said restart means determines the restart frequency according to the driven rate detected by said pump speed detection means.

7. A water supply system as set forth in claim 2, characterized in that wherein said water supply state detection means for detecting the water supply state of the pump is a flow detector for detecting a water supply amount of the pump at a discharge side thereof, and said restart means determines the restart frequency according to the water supply amount detected by said flow detector.

8. A water supply system as set forth in claim 2, characterized in that said water supply state detection means for detecting the water supply state of the pump is means for detecting a daytime operation predetermined to cause the water supply amount of said pump to be increased and a nighttime operation predetermined to cause the water supply amount of the pump to be decreased, and said restart means sets the restart frequency in said daytime operation to be smaller



than the restart frequency in said nighttime operation.

9. A water supply system as set forth in claim 1, characterized in that said fault monitoring means includes output means for informing the other inverter device of the fact that one inverter device was stopped by its own protection means and input means for receiving a message telling that the other inverter device was stopped by its own protection means, and said restart means includes output means for outputting a restart command signal to the other inverter device and input means for receiving a restart command signal from the other inverter device.

10. A water supply system as set forth in claim 1, characterized in that said restart means, when said inverter device was stopped by its own protection means, restarts the stopped inverter device a predetermined constant time after stoppage of the inverter device.

11. A water supply system as set forth in claim 1, characterized in that said restart means, when said inverter device was stopped by its own protection means, restarts the stopped inverter device by the number of times corresponding to a frequency within a predetermined frequency range.

12. A water supply system characterized by comprising:

a plurality of inverter devices having protection means for protecting themselves for



generating variable frequency AC power according to a preprogrammed drive schedule;

a plurality of motors connected to said inverter devices for being driven with a variable speed when receiving power from said inverter devices; and

a plurality of variable speed pumps connected to said motors for supplying water to a tap water distribution pipe,

wherein each of said inverter devices includes fault monitoring means for monitoring operation of said protection means of the other inverter device, restart means for outputting a start command to the other inverter device which fault was detected by said fault monitoring means by the number of times corresponding to a frequency within a predetermined restart frequency range, and means, when the other inverter device fault-detected fails to be restarted even after the number of times of outputting said start command reach said predetermined restart frequency, for operating the other normal inverter device in place of the stopped inverter device.

13. A water supply system characterized by comprising:

a plurality of inverter devices having protection means for protecting themselves for generating variable frequency AC power according to a preprogrammed drive schedule;

a plurality of motors connected to said



inverter devices for being driven with a variable speed when receiving power from said inverter devices;

a plurality of variable speed pumps connected to said motors for supplying water to a tap water distribution pipe; and

means, when any one of the inverter devices is stopped by its own protection means, for operating one of the other normal inverter devices in place of the stopped inverter device.