

[54] METHOD OF EFFECTING FAST TURBINE VALVING FOR IMPROVEMENT OF POWER SYSTEM STABILITY

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Related U.S. Application Data

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[52] U.S. Cl..... 290/40, 317/21, 60/105

[51] **Int. Cl.**..... **F01k 13/02**

[58] **Field of Search** 290/2, 52, 40; 317/21;
307/92: 60/105

[56] **References Cited**

UNITED STATES PATENTS

3,421,014	1/1969	Moorganou.....	290/40
3,515,893	6/1970	Park.....	290/40

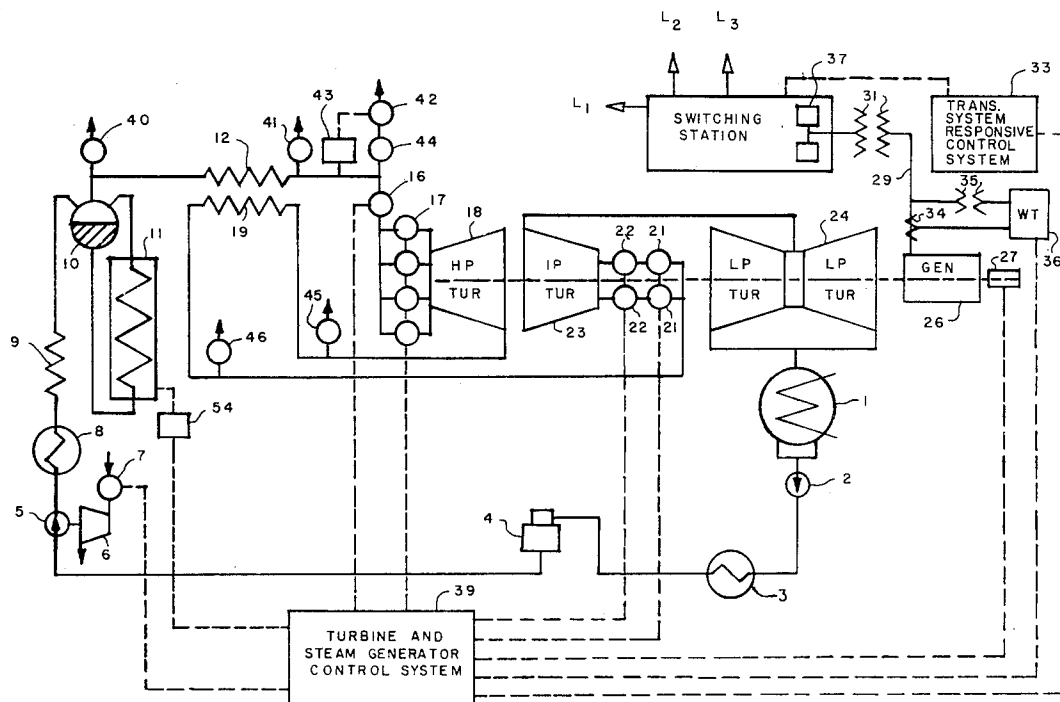
Primary Examiner—G. R. Simmons

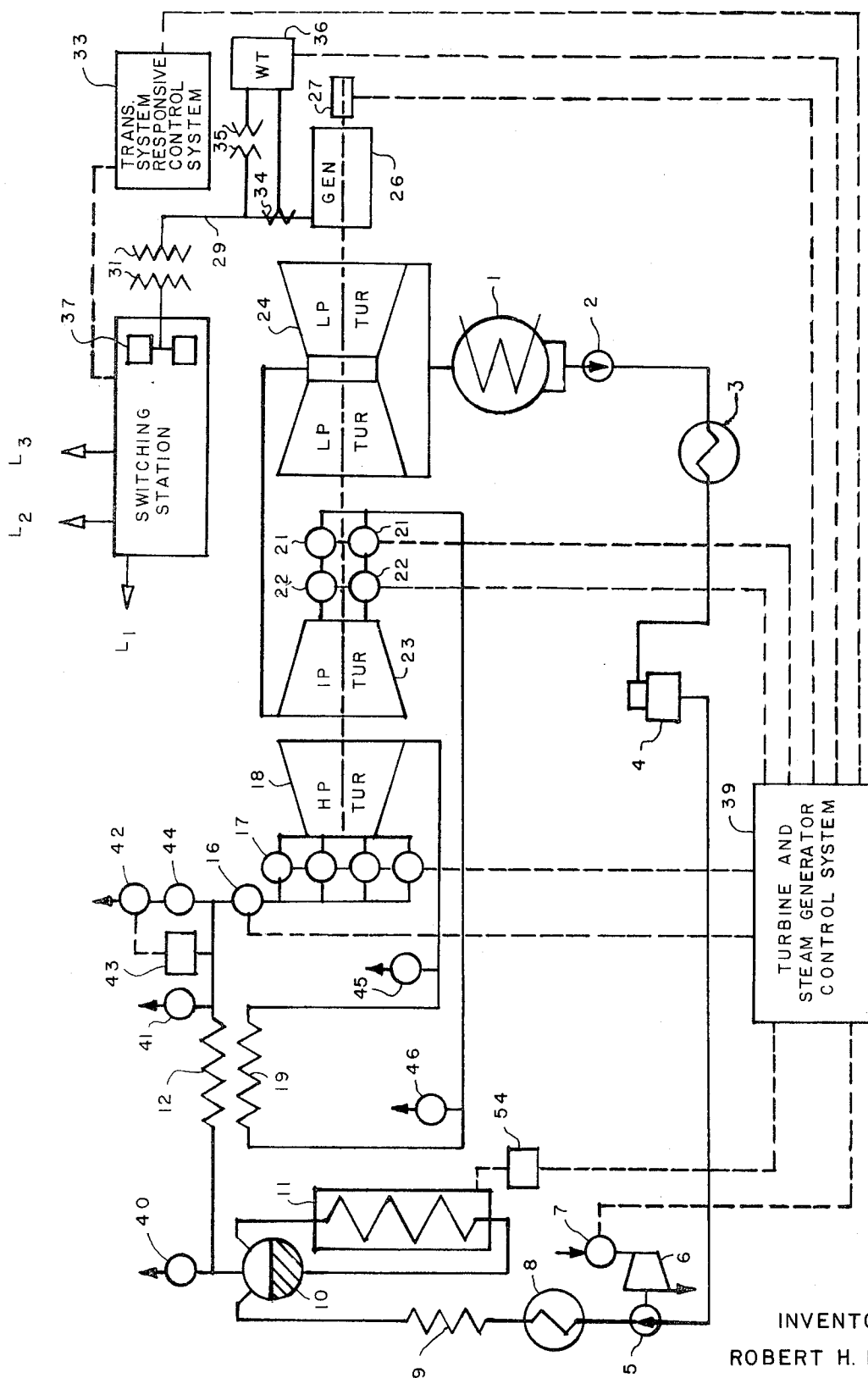
[57] **ABSTRACT**

As an improved way of effecting fast valving of turbines of power system steam-electric generating units for the purpose of improving the stability of power

transmission over transmission circuits to which their generators make connection when stability is threatened by line faults and certain other stability endangering events, and in which intercept valves are rapidly closed on a momentary basis, the procedure of intercept valve closure is supplemented by simultaneously initiating turbine and steam supply source control programs which (a) bring into effect a sustained reduction in turbine driving power via employment of measures which may include full closing of some or all control valves and/or employment of preprogrammed control valve repositioning, with provision to automatically divert high pressure steam to the condenser or to atmosphere as a way to prevent discharge of steam through high pressure safety valves, (b) bring into effect a rapidly executed process of reduction of rate of generation of steam within steam supply sources, and (c) initiate a control program that effects a predetermined degree of partial reopening of intercept valves early in the course of the generator rotor's first backward swing, following which intercept valves are further opened and control valve positions optionally revised in preprogrammed ways with the overall effect that in the period following the first forward swing the magnitude of turbine driving power is caused to hold below the value that applied prior to the event that initiated fast valving and to at most only briefly exceed a final sustained value that can be pre-set.

16 Claims, 5 Drawing Figures





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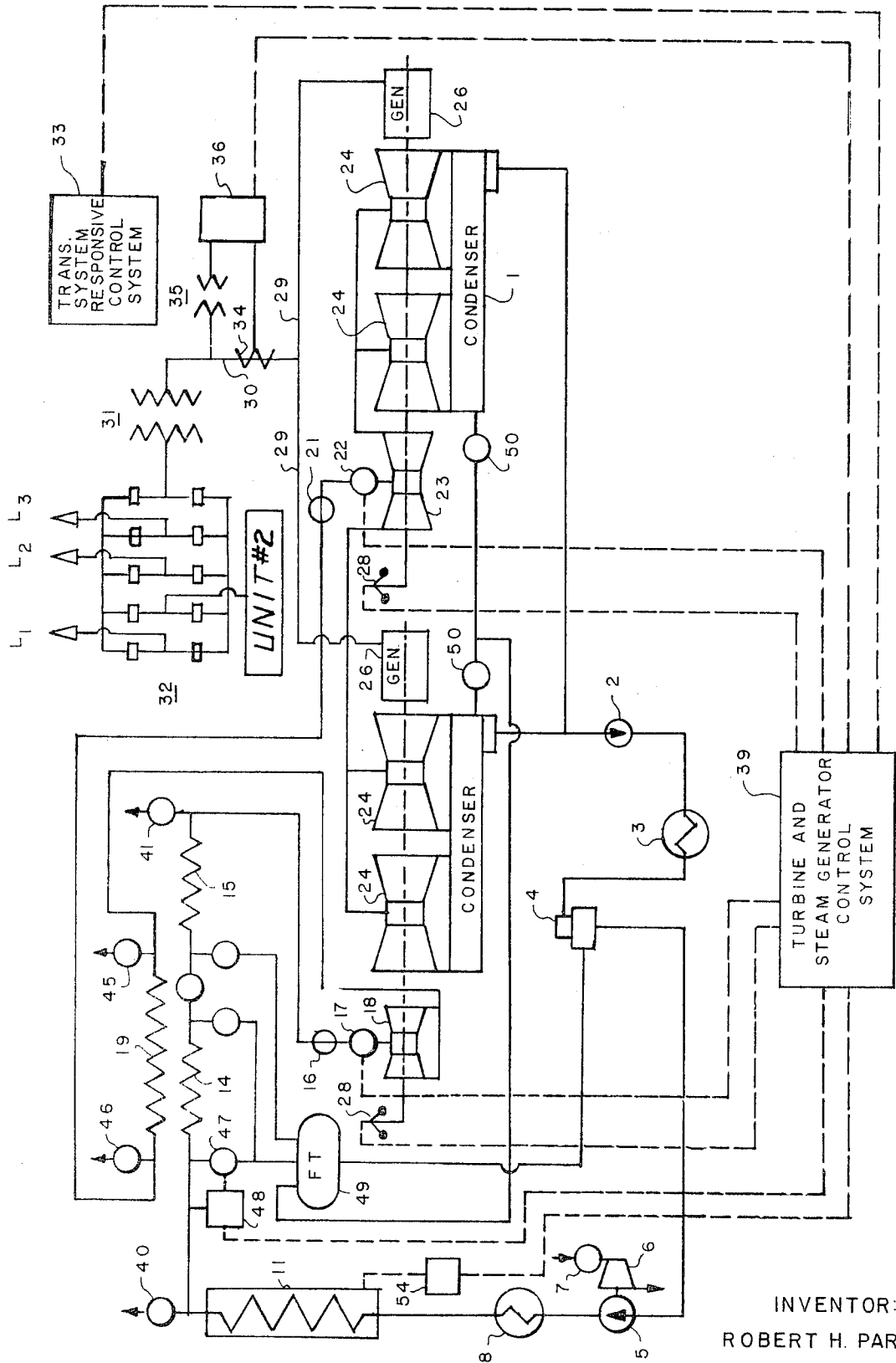
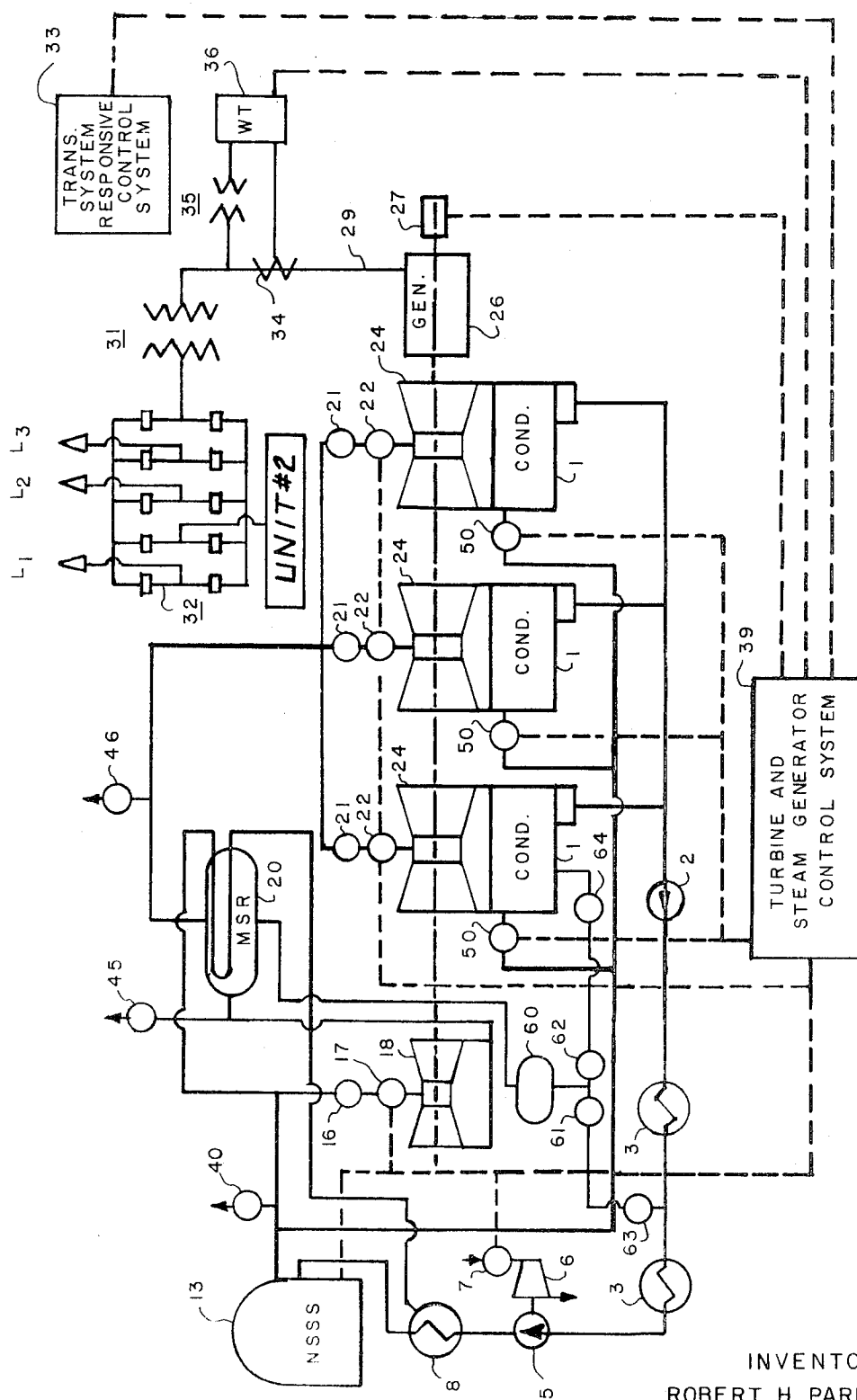


FIG. 2

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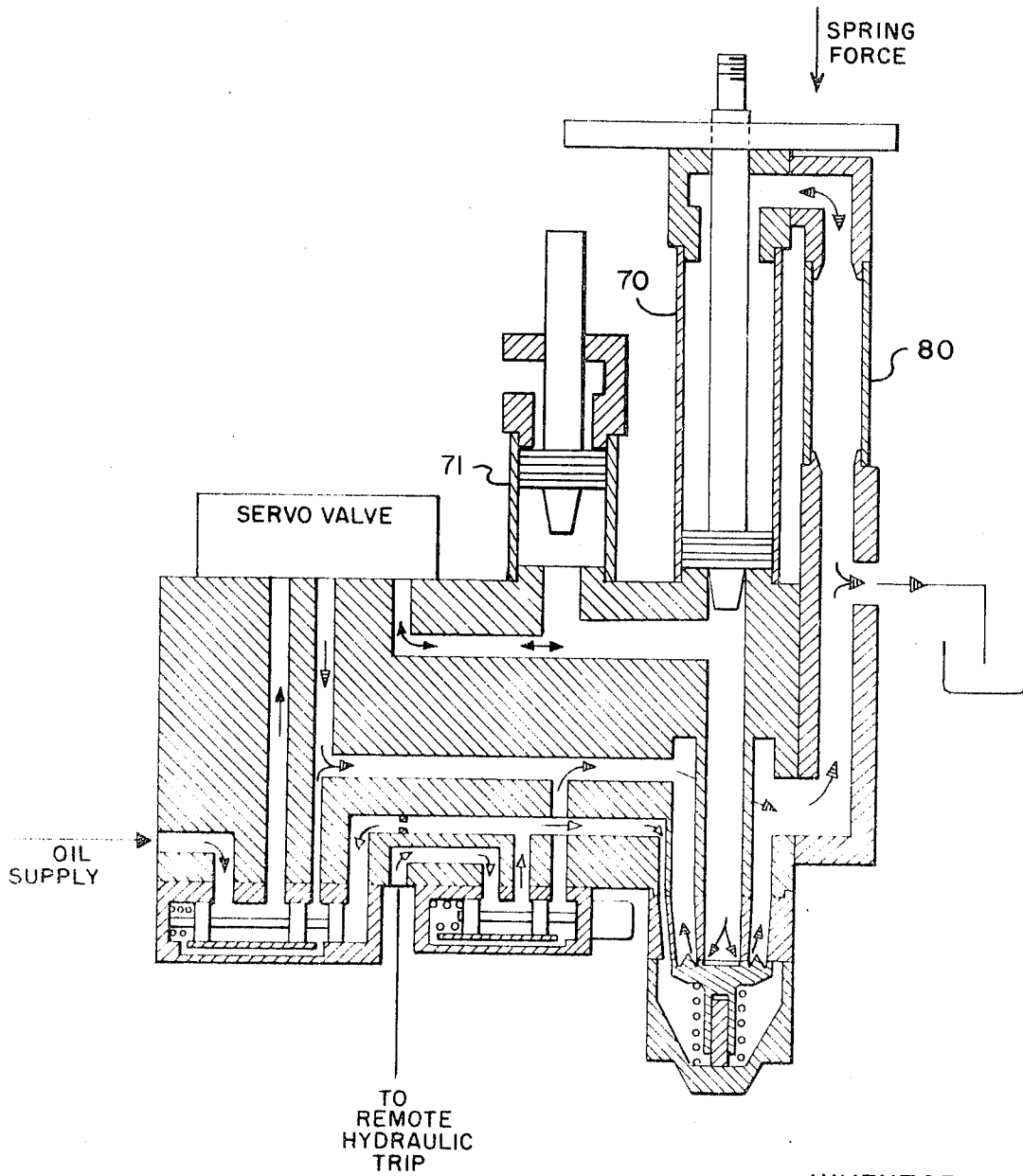


FIG. 4

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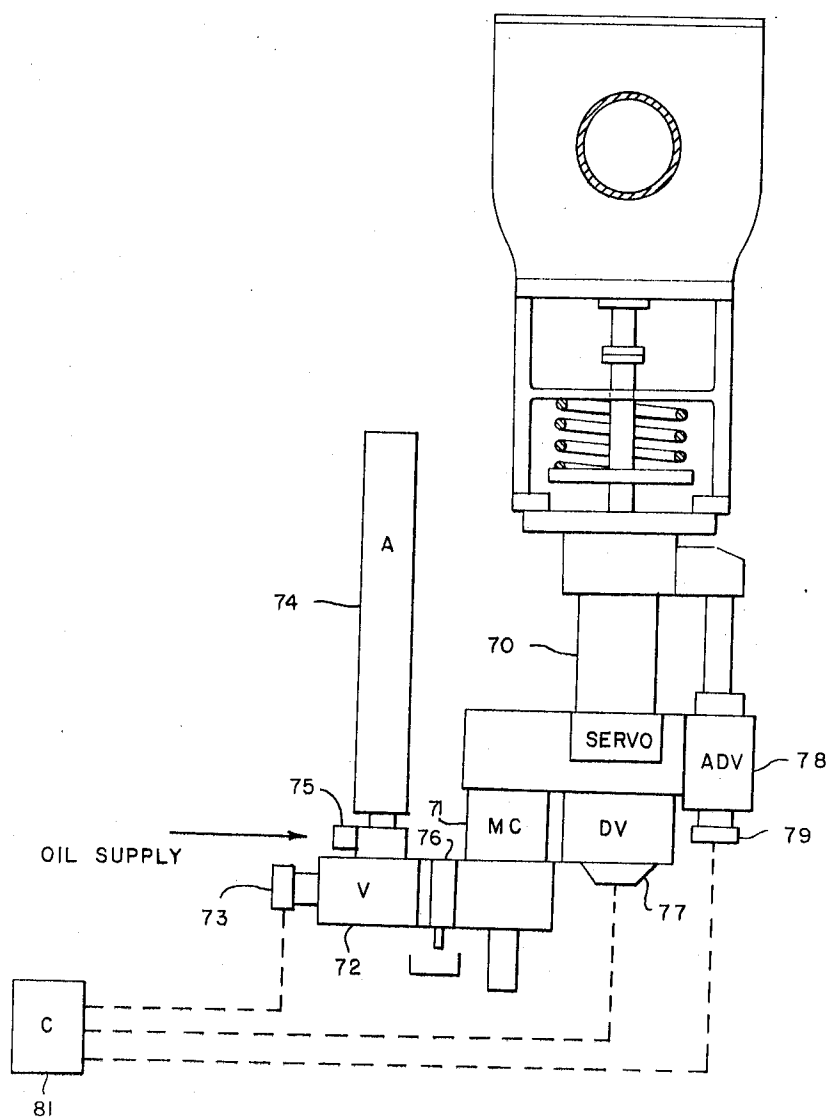


FIG. 5

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METHOD OF EFFECTING FAST TURBINE VALVING FOR IMPROVEMENT OF POWER SYSTEM STABILITY

CROSS REFERENCE TO RELATED INVENTIONS

My invention relates in its principal aspect to means for rapidly controlling power flow within power transmission elements of interconnected power systems with a view to favorably affecting the stability of such systems when jeopardized by suddenly occurring adverse events. This patent application is subject matter related to my issued U.S. Pat. Nos. 3,051,842, Re. 26,571, 3,515,893, which has reissued as Re 27,482 and 3,657,552, and is a continuation in part of my copending U.S. Pat. application, Ser. No. 244,594 filed Apr. 17, 1972.

BACKGROUND OF THE INVENTION

1. Field of Invention

The area of utility of the invention comprises prevention of development of system instability within power systems when threatened by transmission line faults, and certain other system stability endangering events.

The area of method comprises responding to faults and other events that could endanger system stability by rapidly initiating preprogrammed processes of

- a. full or partial closure of valves controlling input of steam to steam turbine type generator prime movers of power systems, effected within $\frac{1}{4}$ second, followed by full or partial valve reopening, effected within a matter of one or more seconds, with provision of valves that automatically by-pass steam either to the condenser or to atmosphere as a way to prevent discharge of steam through high pressure safety valves,
- b. effecting a sustained reduction of the rate of steam generation within steam supply sources within a period of 5 to 15 seconds up to as much as one minute more.

2. Prior Art

First published prior art in the area of fast prime mover driving power control for stability improvement came in 1929 (1) (Numbers in parentheses refer to Table of References.) and the first published description of a successful reduction to practice in 1931 (2).

U.S. Pat. No. 1,935,292 which issued in 1933 (3), in which a Pelton wheel was shown as the source of driving power, provides a good picture of early control concepts.

Reference 4 is mainly of interest in that it had the effect of deflecting interest from both fast turbine valving and momentary application of braking load.

Reference 5 which was published in 1934 cited the findings of reference 2, and led to a sequence of USSR studies of fast steam turbine valving for system stability improvement (5, 6, 7, 10, 11, 12, 13, 17), and one U.S. patent (18).

In 1962 reference 21 introduced the concept of providing to vary the nature of a preprogrammed process of turbine valving in response to the extent and distribution of prefault transmitted load.

In 1966 reference 22 which was reissued in 1969 (23) introduced the concept of employing fast valving

and braking load in combination, and of preprogrammed response to the post-fault event of unsuccessful reclosure of faulted line circuit breakers.

Beginning in 1961 the writer undertook to solicit interest on the part of power producers and turbine generator manufacturers in fast turbine valving optionally supplemented by momentary application of braking load.

Meetings were held with GE and Westinghouse engineers and, following the 1965 Northeast U.S. blackout, GE engineers presented a paper on fast valving at the 1966 American Power Conference (24).

This 1966 GE paper stimulated interest in fast turbine valving on the part of a number of U.S. power producers, and led to the publication of several papers (25, 26, 27, 28, 29, 30).

In February 1966 the writer filed a patent application which issued as U.S. Pat. No. 3,515,893 (31), and subsequently filed for reissue of this patent (32) and in 1968 presented a paper at the American Power Conference (33) which dealt in large measure with what had been set forth in the application for the patent.

As early as April 1964 the writer began to look into what was available in the way of power operated relief valves both that could be used to divert or dump high pressure steam to atmosphere or the condenser as a way to prevent discharge of steam through high pressure safety valves when high pressure turbine steam acceptance was reduced by closure of control valves, and in reference 31 cited the concept of programming initiation of the opening of such valves as an aspect of fast valving control procedures (as see reference 34 column 19 par. 2).

A 1966 review of U.S.S.R. references revealed that, as of 1965, in the U.S.S.R., certain once-through steam-electric installations were equipped with fast acting valves that would by-pass steam around the high pressure turbine to the cold end of the as control valves closed, thereby avoiding both safety valve lifting and boiler problems, and at the same time would by-pass steam from the hot end of the reheater to the condenser, (14, 15) using, for the purpose, valves of a special type that incorporated provision for desuperheating and that, as it later appeared, were at that time being provided in once-through type boilers of German steam electric installations where they were used during startups and to make possible sudden step reductions in unit load (35, 39). This type of valving, therefore, represented one approach to a solution of the problem of safety valve lifting though not an approach that could easily be applied in U.S. type steam-electric installations.

In 1966 the writer ran into the fact, that whereas in once through type boilers it is practice to provide by-pass valves to the flash tank of the boiler, for the purpose of discharging water to the flash tank during the startup process, the point applied that when these valves are opened under load conditions, steam passes through them to the flash tank and thence to the condenser, which suggested that it might be that, since Babcock & Wilcox's once through boilers are equipped with fast acting (air operated) type valves that by-pass the primary superheater, fast initiation of their opening might operate to prevent safety valve blowing on fast closure of turbine control valves, or, at any rate, that this could be the case if fast closing was promptly followed in sufficient degree by fast partial reopening.

The fact that fast opening of the valves in question could prevent safety valve lifting was eventually confirmed, when, in 1969, tests on a 600 megawatt steam-electric unit incorporating a Babcock & Wilcox oil fired boiler demonstrated that with use of preprogrammed fast opening of the primary superheater by-pass valves it was possible to trip the unit at full load without blowing safety valves, and, by, at the same time, reducing oil supply to 10 per cent in 8 seconds, after another minute or so, resynchronize and begin to reload, and fully reload in 20 minutes (37).

Moreover based on unpublished information which the writer had been furnished by the GE in 1966 (38) to the effect that a 50 percent sudden step reduction of turbine driving power would not cause significant damage to fossil fuel type turbines. Also information was obtained from Babcock & Wilcox he was aware of the fact that even for the case of coal firing, a 40 to 50 per cent reduction in fuel feed could be achieved in rapidly enough to avoid development of excessive reheater and superheater temperature.

Putting all these facts together made it appear that fast turbine valving of a type that would effect no more than a 40 to 50 per cent sustained step reduction of the steam acceptance of a high pressure turbine of any fossil fuel steam-electric installation, whether or not coal fired, would represent an entirely feasible thing, and that in the case of Babcock & Wilcox once through boilers already equipped with fast acting by-pass valves, also something that would involve little expense.

This information was communicated to the Tennessee Valley Authority, with which the writer had and presently retains a consulting arrangement, and eventually led to a decision to apply the scheme to unit No. 2 of TVA's Cumberland generating station (36).

The information contained in reference 37 was also furnished to the Chief Mechanical Engineer of Southern California Edison, in the context of employment of the principle of fast opening of the by-pass valves to the flash tank of the Babcock & Wilcox boilers of two jointly owned 800 mw steam-electric units located in the Four Corners, New Mexico plant of Arizona Public Service, as a hitherto unrecognized as feasible, very simple way to provide the steam by-pass capability needed to allow fast valving these units to half load, whereby to avoid need to trip-off one unit in response to the occurrence of a fault on the 500 kv line leading from Four Corners to Los Angeles and do so while avoiding lifting of safety valves.

Also the writer supplied a copy of reference 37 to a Working Group of the System Design Task Force of the New England power systems, that had been directed to carry out a study of fast valving. However in their report of their studies, though the Task Force discussed what was disclosed in reference 37, this was done only in the context that it demonstrated feasibility of tripping turbine generators of once through steam-electric units to auxiliary load and rapidly resynchronizing and reloading (40).

The above and other information that could be cited makes evident that it was not obvious to the power systems engineers involved that in the case of once through boiler type steam supply systems of U.S. type were viable ways to employ fast turbine valving of a type in which a program of rapidly executed control valve momentary and sustained partial closure was

made use of as a way to prevent loss of system stability and avoid need to trip-off generation, while avoiding lifting of safety valves, and that, in the case of Babcock & Wilcox once through type boilers, this could be done without need to provide by-pass valve capability beyond or different from that already available.

Moreover non obviousness of the feasibility of safely employing fast control valve closure either on a momentary or sustained basis is confirmed by reference 24, which, though it cited the start-up by-pass system, did so only in the context of its function as something adapted to protect the boiler, rather than as a potentially effective means of preventing lifting of safety valves (41), and also be reference 29 which advises that the GE stand is in opposition to employment of fast reduction in high pressure turbine steam acceptance via "fast action in the control valves as a supplement to fast closing of intercept valves" and cited by way of explanation "possible repercussion on the boiler safety valves and boiler control" (42), a view that is also expressed in reference 27 (43).

Also it is interesting to note that references 24 through 30 and reference 40 as well, fail to propose turbine control valve momentary full or partial closure as a way to prevent discharge of steam through reheater and moisture-separator-reheater pressure safety valves and a chance of need to schedule a shut down for valve maintenance, when fast valving is effected.

Thus U.S. engineers have shied away from employment of fast control valve repositioning as an aspect of fast turbine valving for system stability improvement based on the opinion that problems that could not be readily solved stood in the way, and for this reason have favored restriction in the scope of fast valving procedures notwithstanding on the basis of this policy benefits that fast valving could provide when control valve repositioning is employed could not be realized.

The present invention shows how penalties that were visualized as applying when control valve repositioning is employed as an aspect of fast valving for system stability improvement can in some cases be gotten around with the benefit of only minor changes in boiler and turbine control systems and methods, and how also, where this is not feasible, costs involved in providing needed fast acting steam by-pass capability can be minimized.

When it comes to the changes in turbine control measures proposed in the present invention these include the concepts of rapidly partially reopening control and intercept valves.

In this connection the concept of merit in rapid reopening of intercept valves, with initiation of opening occurring at or in advance of the first forward swing of the generator rotor, appear to have been first publicly noted as desirable in reference 13 and was also noted in references 46, 47 and 49. However as going beyond what is put forward in those references the present invention calls, as suggested in reference 48 and 50, for at first rapidly opening intercept valves part way, and thereafter reopening them more slowly, and goes on to explain how this objective can be implemented.

While not a matter of public record it may be worthy of note that, as was brought out in a memo prepared by the writer and dated March 11th, 1964, copies of which were sent to Westinghouse engineers, the desirability of providing for the fast partial lifting of intercept valves was put forward in a Mar. 5, 1964 meeting with Wes-

tinghouse engineers and a representative of Westinghouse's Patent Dept.

In the memo the writer stated that his "fast governing" concept "would ideally call for" among other things

- A. Valve closing in response to an electrical signal such as an indication of a line fault
 - a. Rapid closing of control and intercepting valves, as in a matter of $\frac{1}{4}$ second, followed by timed initiation of reopening, at the same rate, after a time interval in the range $\frac{1}{8}$ to $\frac{3}{4}$ second from the initiating signal
 - b. Reopening at equal speed to a controlled valve opening which could correspond to a load equal to or lower than that prevailing prior to the initiation of closing operations.

Here the idea of providing for a variation in dead time was to allow for the fact that, as is well known to system planners, in some situations generator rotor swings peak as in 0.4 seconds, and in other cases, more slowly as in as much as 1 second, or more, with the effect that where slow enough peaking can be expected, a $\frac{3}{4}$ second delay in intercept valve reopening can be useful.

In the light of the foregoing the rendering feasible of employment of fast momentary and partial control valve closure by the methods which the writer has briefly outlined, and which are characterized by the fact that they are well adapted to implementation in the context of U.S. designs of steam-electric installations, as also the improvement of effecting fast only partial control and intercept valve reopening, which include among their advantages prevention of development of loss of synchronism on generator rotor swings subsequent to the first, are viewed as novel and non obvious, and moreover the same is also thought to apply to the concept of effecting a sustained reduction of the driving power of turbines of BWR nuclear and other steam-electric installations by delaying full opening of intercept valves while tolerating discharge of steam through low or intermediate pressure safety valves over a period during which rate of generation of steam within the steam supply source is in process of being reduced on a preprogrammed basis.

In relation mainly to the prior art of fast valving taken as a whole, it may be in order to, at this point, take note of reference 18 comprising U.S. Pat. 3,421,014 which issued on Jan. 7, 1969.

This patent describes methods of fast valving steam turbines for system stability improvement which operate via employment of a feed-back type of control system, rather than a system of feed-forward type which characterize fast turbine valving techniques disclosed in the writer's patents and pending patent applications.

Also the patent in question makes no reference to steam by-pass systems, or to fast control of rate of steam generation within steam supply sources, even though in references 8, 9, and, apparently, also in 10, the inventor describes by-pass valve arrangements that allow discharging entrained steam to the condenser through the turbine's intercept valves.

From the above it does not appear that the patent anticipates what is set forth and claimed in the present application, while also this applies, as well, to what is set forth in references 8, 9 and 10.

Another point that may be worthy of note is that while in German once-through boiler type steam elec-

tric installations which incorporated what can be termed German type by-pass systems provision was made for simultaneous fast closure of control and intercept valves, as in the case of U.S. Pat. 3,421,014 which has relation to USSR practice, valve repositioning was brought into effect on a feed-back basis, in response to speed increase, rather than in a preprogrammed manner adapted to cause valve position changes to take place independently of speed change.

Also it may be worthy of note that, in the period 1966 through 1968 the writer discussed the concept of rapidly effecting preprogrammed sustained reduction in the steam acceptance and driving power of the turbines that would be equipped with German type by-pass systems, in meetings with engineers of the consulting firm Ebasco Services, with engineers of Combustion Engineering and with the Chief Mechanical Engineer of Southern California Edison.

However, in the U.S., this type of by-pass system though at one time given a trial in a Combustion Engineering boiler was not viewed as worthy of use in U.S. installations based on the fact that expense would be high and that the valves could leak.

In 1969 the Chief Electrical Engineer of Ebasco Services helped to arrange so that the writer could meet at the 1969 American Power Conference with the author of reference 35, a representative of Siemens, and at this meeting and subsequently the writer endeavored to interest Siemens in offering provision for preprogrammed fast valving to potential turbine-generator purchasers.

Later at the 1971 ASME- IEEE Joint Power Generation Conference the writer contacted the author of reference 65, and also representatives of the German turbine generator manufacturing firm of M.A.N. who were attending the meetings.

These contacts with Siemens and M.A.N. personnel, were supplemented by correspondence, and the transmittal to these firms of copies of references dealing with fast turbine valving, of preprogrammed type, as a way to improve system stability, but this activity on the part of the writer elicited no evidence of action when it came to dealing with potential customers.

This presumably, was due in part, to the fact that, whether in the U.S., or Germany, the subject of power system stability, typically, has hardly at all been understood by mechanical engineers of turbine generator manufacturing establishments.

At the present point in time the potentiality of fast valving for stability improvement is beginning to become clear to Europeans, as see in this connection, sections 3.4, 3.5 and 5.8 of reference 66, and it will certainly be obvious to Europeans that fast closing and opening of control and intercept valves can easily be provided where German type by-pass systems are used.

Also in U.S. high temperature gas cooled, or HTGR, nuclear installations, German type by-pass systems are used, and it will be obvious how to apply preprogrammed fast control and/or intercept valve closing in these installations, as a way to improve power system stability.

However, though it would be obvious, in the light of the prior art, to provide fast open valves subsequent to fast closure, there appears to the writer, to be no evidence that it would be obvious to rapidly reopen intercept valves part way and thereafter more slowly.

For this reason, in this application, when it comes to claims on fast partial reopening of intercept valves, the claims have not been restricted to apply to any particular type of steam electric installation, turbine or by-pass system.

SUMMARY OF THE INVENTION

The invention has relation to improved methods for rapidly varying the driving power of turbines by repositioning control and intercept valves, and for simultaneously controlling the operation of steam supply systems whereby to avoid development of power system instability when jeopardized by transmission line faults and other stability endangering events, while at the same time avoiding damage to equipment.

Generator drive systems of power system steam-electric installations comprise a high pressure turbine, plus one or more low pressure turbines, plus, in the case of installations in which steam is generated with use of fossil fuel, or a HTGR type nuclear steam supply system one intermediate pressure turbine.

Steam reheaters are located ahead of intermediate pressure turbines, and moisture-separator reheaters ahead of low pressure turbines of nuclear that utilize BWR and PWR nuclear reactor installations

Control valves are employed to control supply of steam to high pressure turbines and intercept valves are provided immediately ahead of intermediate pressure turbines and low pressure turbines of nuclear installations that utilize BWR and PWR.

In the U.S., at least it, is common practice for the first stage of a high pressure turbine to be of the impulse type and for first stage nozzles to be grouped into segments with the steam supply to each segment individually controlled by means of individually operable control valves.

It also was at one time a common practice and it remains feasible to employ by-pass type control valves that admit high pressure steam to intermediate stages of high pressure turbines.

Providing to automatically momentarily close intercept valves in response to an indication of a line fault offers a way to decrease the tendency for power system generators to lose synchronism as a result of line faults and other system stability endangering events, but such momentary closure tends to increase pressure within reheaters and moisture separators, with two effects,

1. the post-fault or more generally the post stability endangering event driving power of the turbine or turbines down stream of the intercept valve or valves will exceed the pre-fault, or pre-event driving power, a circumstance which tends to adversely affect system stability, this being especially the case when the fault or other stability endangering event results in the sustained opening of one or more transmission system circuit breakers, and thereby operates to impede transmission of power in the post-fault or post-event regime, whereas actually it would normally be advantageous for the total post-fault or post-event driving power of the turbine to be held less than, and, as a rule, preferably somewhere in the range of 60 to 90 per cent of pre-fault or pre-event value,
2. reheat and MSR (moisture separator and moisture separator reheater) pressure safety valves may discharge steam and in some cases may thereafter leak and require maintainance.

One proposed approach to the solution of problem (2) above is to speed up the process of intercept valve reopening, while another is to raise the setting of the reheater and MSR pressure safety valves.

However these approaches do not solve problem (1).

An obvious way to avoid both problem (1) and (2) is to reposition control valves so as to reduce high pressure turbine steam acceptance on a sustained basis.

However, as explained under the heading of Prior Art, there has been reluctance on the part of engineers to employ this procedure because of the conviction that it would be difficult and expensive to provide so that it could be effected without lifting of high pressure safety valves, which, when occurring, is likely to cause damage to the valves that can require scheduling a unit shutdown to allow effecting repairs.

Also, in the case of fossil fuel fired installations, there has been concern as to the feasibility of readjusting fuel, water and combustion air supply rapidly and accurately enough to prevent damage to reheaters due to overheating, and as to whether what would be done would cause objection from the standpoint of excessive thermal fatigue damage to turbines.

In the present invention the problems presented are dealt with by providing for the use of power operated valves that are caused to open and close in response to steam pressure and that are arranged to automatically divert high pressure steam to atmosphere or the condenser fast enough to protect against discharge of steam through high pressure safety valves when control valve closure is put into effect and by employing a method of fast valving which brings into effect jointly executed preprogrammed processes of,

1. control as well as intercept valve closure which are fast enough to have a favorable effect on generator rotor first swing stability, supplemented by rapidly executed partial reopening of intercept valves, so effected as to cause turbine driving power subsequent to generator rotor first swing to hold below the driving power that applied prior to the disturbance that resulted in initiation of fast valving, while at the same time minimizing generator rotor first backward and second forward swing, (13, 49 and 50), and avoiding lifting of low pressure safety valves, (48).
2. fast runback of rate of steam production within the steam generator to a value that is low enough that diversion of steam to atmosphere or the condenser would terminate.

With implementation of control and intercept valve repositioning taking the form of some or all of several types of procedures as listed below,

- a. fully closing all or only some control valves in a fraction of a second by rapidly opening valve actuator oil dump valves,
- b. fully or partly closing all control valves under servo control,
- c. after initial full or partial closure of all or some control valves, repositioning under servo control,
- d. supplementing item (c) by fast partial control valve reopening effected within $\frac{1}{2}$ second of initiation of closure with control of extent of reopening determined with use of metering cylinders or with servo or cam operated valves,

- e. fully closing all intercept valves in a fraction of a second by rapidly opening valve actuator oil dump valves, or
- f. fully or partly closing all intercept valves under servo control,
- g. after initial full or partial closure of intercept valves, fully reopening within a period of some seconds,
- h. supplementing item (g) by fast partial intercept valve reopening initiated somewhat in advance of the instant of generator rotor first forward swing, and effected within $\frac{1}{2}$ second, with extent of reopening determined with use of metering cylinders or with servo or cam operated valves.

In addition it is a feature of the method of fast valving that comprises the present invention to optionally pre-program processes for effecting sustained reduction of turbine driving power which would tolerate short term discharge of steam through low or reheat pressure safety valves, and in this way avoid or minimize need to close control valves, and to provide fast means of diversion of high pressure steam.

A main object of the invention is to allow, via provision in generating station design, so that power transmission lines can be subjected to higher transmitted power loadings than could otherwise be employed without a consequent increase in hazard of development of system instability on the occurrence of line faults and certain other system stability endangering events.

Another object is to increase the amount of power than can be safely transmitted over a right of way of given width.

A further object of the invention is to allow increasing the amount of power than can be transferred over a line operated at a given voltage.

Another object of the invention is to provide so as to minimize hazard of development of system instability in the event of infrequently occurring severe contingencies such as delay in fault clearance.

Another object of the invention is to achieve the above objectives in a manner that minimizes generating station first and operating costs including costs related to providing for steam by-passing and for discharging steam to atmosphere via power operated valves, and that avoids need to take generating units out of service to allow repairs.

Another object of the invention is to provide improvements in generating station design which increase effectiveness and eliminate or minimize penalties in employment of fast turbine valving, whether or not supplemented by employment of dynamic braking, whereby to prevent cascading type system instability.

Still another object of the invention is to avoid development of system instability subsequent to the occurrence of first generator swings following a line fault or some other system stability endangering event.

Still another object of the invention is to avoid situations where, even though a generator remains in synchronism following a fault on a line tying it to a system, the disturbance resulting from the fault has the effect of causing loss of synchronism of some other generator or generators.

It is an important element of the invention that it can be usefully employed as an aspect of a process of combined fast valving and momentary application of braking load.

BRIEF DESCRIPTION OF THE DRAWING

The subject matter which is regarded as the invention is capable of being implemented in a variety of ways.

- 5 In practice what is necessary to facilitate its employment is to devise ways to apply it in power system steam electric installations of already developed types, with a minimum need to introduce changes in design that would be costly and time consuming to put into effect.

Therefore the drawings have been prepared in this context.

In the drawings

- 15 FIG. 1 is a simplified schematic view of a typical fossil fuel type steam turbine driven generating unit of U.S. design to which is coupled a drum boiler type of steam generator,

- 20 FIG. 2 is a simplified schematic view of the No. 2 unit of TWA's Cumberland generating station in which a Brown Boveri cross compound turbine receives its steam from a Babcock & Wilcox once through steam generator,

- 25 FIG. 3 is a simplified schematic view of a large nuclear turbine which is supplied with steam from a nuclear steam supply source which could be of either the boiling water (BWR) or pressurized water (PWR) reactor type,

- 30 FIG. 4 is a simplified partial representation in schematic form of an arrangement adapted to rapidly reopen a closed turbine steam admission valve but do so part way only,

- 35 FIG. 5 represents an exterior view of an intercept valve that has been provided with means for effecting fast partial reopening.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

- 40 In FIG. 1 water that has drained down to the bottom of condenser 1 is pumped by pump 2 through low pressure feed water heater system 3 to deaerator 4 from which point it flows to boiler feed pump 5 which is driven by boiler feed pump turbine 6 which receives steam from one or more sources not shown through valve system 7.

- 45 From the boiler feed pump water passes into high pressure feed water heater system 8, next to economizer 9 and next into drum 10 from which it passes to the bottom of and up through furnace 11 and returns to the drum as wet steam.

- 50 The steam so produced next passes through superheater 12, stop valves 16 shown for convenience as a single valve, but normally consisting of four valves one being series connected to each of four control valves 17 of partial admission type high pressure turbine 18, wherein the nozzles ahead of the control stage of the turbine are divided into four segments which are supplied with steam individually through the four control valves.

- 60 After passing through the control valves and the turbine the steam enters reheater 19 and from there flows through a pair of stop valves 21 and series connected intercept valves 22, and then into intermediate pressure turbine 23 and from there to low pressure turbine 24 and from there flows into the condenser where it is reconverted to water. The three turbines are coupled together in line and drive generator 26 which supplies three phase power to three transformers 31 through

generator output leads 29. In the transformer 31 the voltage is stepped up from typically around 22,000 volts to a voltage which is today typically in the range of 345 to 500 kv, and can range up to 765 kv.

The transformer connects to switching station 32 through a pair of circuit breakers 37 and 38, shown conventionally as square boxes, which are to be understood to represent two of a larger number of circuit breakers not shown in the drawing by which the generator makes connection to transmission lines L₁, L₂ and L₃ and, in the bulk of cases, also to at least one other generator located within the same station that houses the generator shown.

Transmission system responsive control system 33 is to be understood to incorporate a protective relaying system which acts to cause the opening of circuit breakers at which lines terminate, on the occurrence of line faults, and in the case of certain other events, and is to be understood to incorporate also fast valving signal generating and logic means which may and usually would be made responsive to one or, more parameters of system prefault or more generally pre-system disturbing event system conditions, such as lines not in service and the magnitude of generated and transmitted power, plus the fact of occurrence of a fault or other event of a type that could endanger system stability, which in the case of a fault can depend on fault type and location, while also the control system may be arranged to respond to the occurrence of a stuck breaker or some other post instant of fault initiation event, or to the extent and distribution of line fault induced reduction in power flow over one or more lines, or in respect to the extent and rate of reduction of the power output of generators, (57, 58).

Procedures of these types and others directed to determining when to initiate and to modify fast valving cycles have already been described in several patents (3, 21, 22, 23, 46, 54) one of which has already expired, while certain additional procedures are described in the writer's pending U.S. Pat. application Ser. No. 244,594.

In addition control system 33 usually receives information by carrier current or some other channel of communication which has relation to power flow over intra and inter system tie lines and as to the power output of other generators located in and remote from the station, which information is used to develop a signal that is created for the purpose of suitably modifying the load reference of the turbine's control system so as to cause the turbine to become a participant in programs of tie line power flow control and system economic dispatch (53).

Also as shown by the dotted line connecting polyphase watt transducer 36 which is connected to current transformers 34 and potential transformers 35 and which generates a signal proportional to generator power output, control system 33 receives such a signal as one of its inputs.

Turbine and steam generator control system 39 receives as inputs the outputs of generator rotor speed transducer 27, which usually appears in the form of a frequency signal which is generated by a magnetic pick-up which is influenced by a toothed gear on the generator shaft, and in addition receives as inputs an output from watt transducer 36 and outputs from transmission system responsive control system 33 which take the form of turbine governor load reference modi-

fication signals generated as aspects of tie line and economic dispatch control systems and also one or more types of signals which initiate fast valving, or that may relate to what will be preprogrammed to be done when fast valving is initiated.

Thus the dotted line that in FIG. 1 runs from transmission system responsive control system 33 to turbine and steam generator control system 39 is to be understood to include as a minimum two channels of information transfer namely one that is used to modify the turbine's load reference system as an aspect of tie line and economic dispatch control systems and at least one fast valving signal transfer channel.

However it is also to be understood that optionally, in addition, the number of information channels can be expanded to allow selective initiation of more than one type of preprogrammed fast valving cycles, and to permit modification of the parameters of such programs in response to such factors as system conditions existing prior to a line fault or other system stability endangering event, and the occurrence and nature of post fault events.

Coming now to the functions of turbine and steam generator control system 39 there are in the first instance to continuously control the position of the turbine's control valves 17 and also valve system 7 of the boiler feed pump turbine 6 and boiler fuel and air supply control system 54, and in addition the position of control and intercept valves in response to fast valving signals where the object is system stability improvement and also as an aspect of turbine overspeed control systems which systems may also provide for control of stop valves 16 and 21 though in the first instance these stop valves are controlled by emergency governors that represent a built-in feature of the turbine.

When it comes to providing to implement fast valving one useful thing to do that has not been provided for in U.S. steam electric installations to date with exceptions in the case of Four Corners (25), and TVA's Cumberland station (36) comprises,

1. effecting a process of sustained partial control valve closure with a view to avoiding development of instability on generator rotor second and following swings and in the steady state following loss of one or more lines, and as a way to avoid need to trip-off a generator such as could otherwise apply.

Also another new but desirable thing to, do is to

2. so provide that the curve of turbine driving power versus time begins to rise at about the time that the generator rotor has attained the peak of its first forward swing so as to reduce the extent of generator rotor first backward and second and following forward swings (56).

Also a further thing that is desirable is to,

3. avoid lifting high pressure safety valves 40 or 41 in order to prevent damage that could require scheduling a turbine shutdown for the purpose of effecting repairs.

Objectives (1) and (3) tend to be in conflict in that reduction of high pressure turbine steam acceptance, such as occurs when control valves close, operates to cause increase in pressure ahead of the turbine.

However provisions, between the superheater and the turbine, of one or more power operated relief valves 42 which often are arranged to make connection to the high pressure steam line ahead of the turbine

stop valve through shut-off valves 44, which can shut to allow relief valve repair, and which are arranged to open when a pressure operated switch in control unit 43 senses the fact that steam pressure in the steam line exceeds a preset value lower than the pressure at which the high pressure safety valve or valves lift, and reclose when steam pressure falls below this preset value, represents one way of defeating safety valve lifting.

But, providing a sufficient number of these valves to prevent lifting of valves 40 and 41 adds to the expense of the station, and especially when, due to sluggishness of servo controlled valve repositioning, it would be useful from a fast valving standpoint to at first fully close and thereafter reposition control valves to a partially open position.

However there is a feasible way around this problem which can be viewed as obviously offering advantages once it is grasped, but that has not given evidence of being at once obvious to those skilled in the art, or who would profess to be skilled in the art of fast valving for system stability improvement, namely to provide to close two out of the total of four control valves that are commonly employed on partial admission type turbines, which brings with it the opportunity to rapidly reduce turbine steam acceptance to around 65 per cent when starting from an initial condition of full load.

Alternatively it can be elected to provide to close only one valve, which however reduces driving power only about 8 per cent or thereabouts.

Broadly the concept is to rapidly close some but not all control valves, so as to take advantage of what is feasible when partial admission is used.

Apparently there would be objection on the part of turbine producers to the rapid closure of more than half but less than all of the turbines control valves so that in practice not more than half would be so closed.

Also it is a feature of the present invention that, at the same time that a pair of control valves, or only one valve, would be rapidly fully closed by valve actuator oil dumping, the load reference of the speed governing mechanism would be rapidly reset and the dump valves rapidly reclosed so as to cause all valves to begin to move toward new preprogrammed positions under servo implemented feed back type control.

How in detail the foregoing can be provided for can be well understood by referring to U.S. Pat. No. 3,602,617 (54) which describes means for rapidly closing both control and intercept valves and for equally rapidly modifying turbine load reference.

Thus, referring to FIG. 1 of the patent, it will be seen that if provision is made to replace the unbalance relay logic therein identified as item 19 by preprogrammed fast valving logic provided within turbine and steam generator control system 39 and to initiate this logic in response to a transmission system responsive control system 33 fast valving signal output, what is wanted will be fully accomplished if

- a. the connections from the logic system to trigger 17 are opened in the case of two (or three) control valves, and
- b. the modifier is preset to bring about the desired sustained partial reduction in turbine load, rather than zero export load, such as the patent stipulates.

Coincidentally with causing control valve repositioning the fast valving signal would be arranged to suitably

modify boiler fuel and water supply by temporarily disabling usual feed back controls and imposing a fast run-back type of control action which will have the effect of readjusting the rate of fuel and feed water supply to new values that will be approximately in balance with the preprogrammed new sustained value of high pressure turbine steam acceptance in the post-fault or more generally in the post system stability endangering event regime, thereby causing termination of discharge of steam through power operated relief valves by virtue of bringing about a drop in steam pressure, while at the same time sufficiently effecting a reduction of the rate of heat input to the reheater as to avoid development of an undue rise in its temperature.

It is not necessary to disclose in this application the details of how runback would be done because means of providing fast runback of fuel and feed water supply, and hence steam generation, have for long been commercially available from leading boiler and/or boiler control producers and at most would require some degree of speeding up (61, 62).

Since if valves 42 open quickly such opening will slow down pressure build up in the superheater, in the interest of getting maximum advantage out of each valve, and hence minimizing the number that would need to be provided to prevent lifting of high pressure safety valves 41, it can also be useful to provide, as via energization of a quick closing time delay reopening relay, so that the fast valving signal causes control units 43 to immediately open valves 42 on a feed forward basis rather than in response to pressure rise, and retain them in open position for a period long enough for the preprogrammed reductions in fuel and feed water supply to take full effect, which perhaps would require a minute or more.

In the U.S. up to now, except at Four Corners and in TVA's newer stations, only the simplest form of fast valving has been provided by turbine-generator manufacturers as a response to customers requests for provision of fast valving as a means of system stability improvement, namely a system in which intercept valves only are repositioned momentarily.

In the case of GE what has been offered has conformed to what is shown in the upper part of FIG. 6 of U.S. Pat. No. 3,601,607 (54) in which initiation of fast valving depends on the magnitude and rate of increase of an unbalance between prefault turbine driving power and generator electrical load under fault conditions.

Actually response to this type of signal tends to be insufficiently selective (59,64) and for this reason it can be useful to employ a fast valving initiation signal provided by a transmission system responsive control system as a permissive control that would supplement response to generator power-load unbalance (64).

Where the fault condition occurs on a radial line or on a weak tie to other systems, control system 33 can recognize this fact, as also the prefault load on the line and from this information, if warranted, generate a fast valving signal that calls for only a small partial sustained or perhaps no sustained reduction in turbine driving power, and perhaps for fast full closure of only one control valve by valve actuator oil dumping, while, if a fault occurs on a strong tie that is carrying a heavy load, system 33 can recognize this condition and generate a signal that calls for a rapid closure of two or even

all control valves by means of dump valve action (31,32,59).

Coming now to providing for fast partial reopening of intercept valves, as a first step it is necessary to provide so that when they are employed intercept valve actuator oil dump valves reclose before reopening can be started, and since it is desirable for intercept valves to begin to open somewhat in advance of the first forward swing of the generator rotor, (48,50) and since time is required in which to bring about valve acceleration in a reopening direction, it works out that in situations where generating stations are interconnected by short lines of extra high voltage, that it can be desirable for dump valves to reclose in as little as 0.05 to 0.10 seconds following intercept valve closure.

Present GE dump valves which conform in design to what is shown in U.S. Pat. No. 3,495,501 (55) and are spring loaded to close, do not reclose until almost a second after the intercept valve closes.

However Westinghouse dump valves which are power operated to reclose do so as rapidly as required, and dump type valves also are commercially available that are equally fast.

Therefore there is nothing to prevent GE from providing sufficiently rapidly acting dump valve means.

Since Westinghouse usually does not control its intercept valve actuators with servo control, and since GE's servo control is slow acting, to achieve the objective of rapidly implemented partial reopening, effected shortly after the peak of the generator rotor first swing, in addition to providing to rapidly reclose intercept valve actuator oil dump valves, it is necessary to provide, via oil accumulators, so that the oil needed to partially reopen the valves can be supplied rapidly enough to cause them to partially open with sufficient speed, and also provide so that the process of rapid opening terminates when the valves reopen only part way, as say when they are 25 to 50 or perhaps 60 per cent open (50).

In the matter of limiting the extent of high speed reopening, one approach that could be employed, would be to provide to admit oil to the valve actuator cylinders through position operated tapered spool decelerating type valves, as are commercially available, that would be arranged to close in response to cam action as the intercept valve opens.

In another and perhaps simpler approach a metering cylinder can be interposed between the valve actuator and the accumulator.

FIG. 4 shows a modification of the intercept valve actuator mechanism shown in FIG. 2 of U.S. Pat. No. 3,495,501 which includes a metering cylinder 71 which when forced down by admission of oil at the rod end will cause oil to flow into valve actuator cylinder 70 and push its piston upward. As shown in the figure to avoid undesirable impact effects the piston of the cylinder is provided at the bottom with the same type of decelerating device, taking the form of a tapered spear protruding from the bottom of the piston, that is provided at the bottom of the actuator piston.

In FIG. 4, for ease of inclusion in the diagram, the cylinder has been shown mounted so that its rod end faces upward.

Actually it would appear to be preferable, however, to mount the cylinder with the rod end down as shown in exterior view in FIG. 5 wherein a pilot operated normally closed two way valve 72 which is electrically opened by energization of electrically controlled valve

73 provides a way by which oil stored in accumulator 74 can cause the piston of metering cylinder 71 to rapidly stroke upward thereby effecting rapid lifting of the piston of valve actuator cylinder 70.

Referring further to FIG. 5, 75 is a check valve which serves as a point at which oil can enter the accumulator from the oil supply system, while 76 is an adaptor that provides for connection of valve 72 to the metering cylinder, and that is with a bleed connection to a drain.

Item 77 represents the slow reclosing dump valve shown as item 10 in U.S. Pat. No. 3,495,501, while item 78 represents a duplicate of valve 72 which can function as an auxiliary fast reclosing dump valve since it is arranged to by-pass oil around the piston of cylinder 70, and is activated to open by energization of electrically controlled valve 79.

By reference to FIG. 1 of U.S. Pat. No. 3,495,501 it will be noted that in FIG. 5 the intercept valve assembly is being viewed from that side at which steam enters the valve, which is the reason why oil return line 80 of FIG. 4, which is item 9 of FIG. 2 of U.S. Pat. No. 3,495,501, is not visible.

The concept behind the showing of an auxiliary dump valve is that if it did not turn out to be easy to modify the valve described in U.S. Pat. No. 3,495,501 so as to render it fast reclosing, this valve could still be retained in use as a way to provide overspeed protection, while employment of fast reclosing as well as fast opening dump valve 78 would be effected primarily as a means of implementing fast valving, though it could also be used to provide a redundant means of closing the intercept valve in response to a condition of overspeed.

In the writers concept valves 72 and 78 could comprise a commercially available very rapidly acting valve that has been widely used for controlling the operation of die casting machinery.

However despite its record of successful use the turbine producer could well prefer to use his own time tried valve as a way to perform the very important function of protection against overspeed, which being the case, the provision of an auxiliary dump valve for control of fast valving which could also function as a redundant means of initiating valve closure in response to overspeed conditions would serve the purposes of fast valving yet could in no way serve to degrade reliability of overspeed protection.

Returning now to FIG. 5, control system 81 is arranged to control the position of valves 73, 77 and 79 through electrical connections shown as dashed lines.

In service use the accumulator contains its normal complement of oil and the piston of the metering cylinder 71 is up against the rod end of the cylinder so that the piston rod is fully extended downward. Also electrically controlled valves 73 and 79 are deenergized and valves 72 and 78 closed.

It is provided that when an event occurs that results in a fast valving signal input to control system 81, valve 79 is energized, which causes valve 78 to open with the effect that the intercept valve closes.

After allowing time for closure to take place, and optionally also ensuring that it did take place by means of a feeler switch which is not shown, the control system energizes valve 73 which causes valve 72 to open whereupon the piston of metering cylinder 71 strokes

upward and forces the piston of cylinder 70 to rise part way.

Next, after a delay period, valve 73 is deenergized which causes valve 72 to close and because oil can slowly drain out of adaptor 76 via its drain connection, the piston of the metering cylinder drops down at a rate governed by the rate of discharge via the drain, which is made low enough so that there is no problem of impact when the piston comes to rest at the end of its stroke, at which stage the fast intercept valve lift assist cycle is complete.

One incidental but not unimportant advantage that the metering cylinder offers relative to a decelerating type valve, that may be worthy of note, is that by providing a supplementary push button control that would act to energize electrically controlled valve 73 the metering cylinder can be from time to time stroked under normal load conditions, and by providing the accumulator with a pressure gauge and observing the pressure drop when stroking takes place it could be easily determined whether or not the accumulator contains its normal content of nitrogen and if it did not, provide to add nitrogen.

Because electrically controlled valves 73 and 79 need to be fast acting, use of an alternating current type of solenoid valve would offer advantages, which however would be in part offset by the need to supply power to these valves by means of an inverter which would take its power from a storage battery. One solution to this problem would be to employ a dc solenoid valve having laminated magnetic components as a way to avoid eddy currents which develop in solid type solenoid plungers and slow down valve operation.

Where intercept valves are of plug type as is customary in fossil fuel type turbines it works out that typically 8 to 10 percent stroke will open the valve enough to pass 35 percent of full load steam with reheat pressure at the value that applies at full load, and that around 13 to 15 percent will supply 60 percent, which means that only a relatively small volume of oil is needed when fast partial valve opening is planned, which implies in turn need to employ only a short metering cylinder and a relatively small accumulator. Also because of the small amount of valve stroking needed, where the point applies that GE intercept valves are provided with servo valves, use of a metering cylinder could be dispensed with if servo controlled stroking rate were increased from their present usual value of 10 seconds full stroke to around 2½ seconds full stroke.

Where intercept valves are not provided with means of servo control the metering cylinder approach would appear to provide a relatively simple solution to the problem of limiting extent of high speed reopening.

So far what has been said on the subject of control valve operation has had relation to U.S. units having partial admission type high pressure turbines which also typically do not have provision for rapid enough stroking of valves under servo control to serve effectively as a way to bring about a reduction of high pressure turbine steam acceptance that will serve the needs of fast valving.

In cases where high pressure turbines are not equipped for partial admission and provide fast enough control valve stroking under servo control to sufficiently limit turbine speed under entire loss of load, as applies in the case of Brown Boveri units, rate of valve closure, when fast valving is initiated for purposes of

system stability improvement, has turned out to be not too low to afford stability improvement based on the fact that the Brown Boveri units in question have had higher specific inertias than steam-electric units of U.S. manufacture.

With servo control available it is possible to fully or nearly fully close control valves and completely or nearly completely close intercept valves, and to also thereafter reopen both types of valves part way, provided that oil accumulators are made use of as a way to ensure sufficiently rapid valve reopening.

The method of accomplishing fast valving that comprises nearly fully closing and thereafter partly reopening control and intercept valves has been provided for in the case of unit No. 2 of TVA's Cumberland station, in which a 1,300 MW cross compound Brown Boveri turbine is supplied with steam by a Babcock & Wilcox once-through boiler, the general arrangement being as shown in FIG. 2 wherein like identifying numbers have like meanings to identifying numbers of FIG. 1.

Numbers not shown in FIG. 1 comprise primary and secondary superheaters 14 and 15, fly ball type turbine speed sensor 28, primary superheater by-pass valve 47, with its control unit 48, flash tank 49 and valves 50 which are arranged to open in response to an excess of flash tank pressure.

From the standpoint of fast valving the important feature shown in FIG. 2 is the nature of the primary superheater by-pass valves provided as an element of the steam generator, which, in the case of the B&W once through boiler that has been provided, comprises an array of fast acting air operated valves which, when opened, allow steam to flow to the condenser via the flash tank, and which, taken together, have proved to have enough flow capacity to prevent lifting of high pressure safety valves even in the event of a turbine trip-off taking place at full load (37).

The fact that these valves both offer this much steam acceptance capability, plus the fact that, unlike superheater by-pass valves provided by two other leading U.S. producers of the power station boilers, they are fast acting, implies that when fast acting valves are provided there is no objection to employing full closing of all control valves, and thereafter reopening part way under servo control over a period of up to 10 seconds which represents the time required for control valves of GE electrohydraulic turbine control units to reopen full stroke.

Thus built in fast superheater by-pass capability eliminates need to purchase and install power operated relief valves at added cost where provision for fast valving of the sustained reduction of driving power type is being made.

As to how to provide so that B & W's fast acting primary superheater by-pass valves are caused to open when fast valving is involved, when fast valving is invoked at Cumberland, B & W's initial approach was to provide so that they open without delay in response to development of a predetermined increase in pressure within the superheater system and reclose progressively as pressure falls.

A modified approach would be to preprogram a process of valve opening, that would be triggered by the fast valving initiation signal, and that of presumed increased effectiveness, that was suggested by the writer, is designed to prevent a rise in, or to somewhat reduce pressure, and that would be followed by a process of

progressive valve reclosing as pressure dropped below a preset value.

Referring now to FIG. 3, which represents a nuclear steam-electric installation, steam supplied by nuclear steam supply source (NSSS) 13 which could be of either the pressurized water reactor (PWR) or boiling water tank reactor (BWR) type flows principally into high pressure turbine 18 while some is diverted to the steam reheat coils located within moisture separator reheater (MSR) 20.

In the figure there is a line from the moisture separator reheater which drains to drain tank 60, from which drain water flows normally through check valve 61 and drain tank level responsive valve 63 into the low pressure feed water system 3, but can also flow to the condenser through check valve 62 and drain tank level responsive valve 64.

Whereas only one MSR is shown, and only one drain tank 60 and associated valving 61 through 64 is shown it is to be understood that in actuality there are two MSRs each with its own drain tank and set of associated valves for each low pressure turbine, or in the installation shown in FIG. 3 a total of six MSRs, six drain tanks and six sets of valves.

Steam that passes through the MSRs enters 3 low pressure turbines 24 via six pairs of stop and intercept valves 21 and 22 respectively.

In PWRs item 40 represents a high pressure safety valve that discharges steam to atmosphere while in BWRs it represents a safety valve that discharges direct to the condenser.

Similarly, in the case of PWRs safety valves 45 and 46 are arranged to discharge low pressure steam to atmosphere, and in the case of BWRs to the condenser.

Items 50 represent groups of by-pass valves that are arranged to open in response to excess steam pressure ahead of the turbine, such as can develop when the steam acceptance of high pressure turbine 18 is reduced by closure of control valves 17.

In the case of PWR reactors of Westinghouse type, at full load steam delivery pressure falls well below pressure at no load and it results that a sufficiently brief momentary full closure of control valves 17, plus a sustained 50 percent reduction in high pressure turbine steam acceptance, will not lift safety valves 40.

On the other hand it is to be understood that if the NSSS is of BWR type the by-pass capability of valves 50 limits, to the capacity of the by-pass system, the extent of even only momentary reduction in high pressure turbine steam acceptance that can be tolerated without scrambling the reactor.

For the above reasons and because by-pass capability is expensive, in the case of those BWRs which do not have 100 per cent by-pass capability, which is the usual situation, and assuming partial admission units are involved, it can be essential to rapidly fully close no more than two and in some cases only one control valve.

In the case of nuclear turbines Westinghouse units employ butterfly type intercept valves which have the advantage that in closing they operate to very rapidly reduce low pressure turbine steam acceptance, but the disadvantage that when opened conventionally at a steady rate over a period of 5 seconds reacceptance of steam by the low pressure turbine is delayed for over two seconds, which, as brought out in reference 50, is disadvantageous and therefore it is important to pro-

vide via fast closing dump valves, accumulators and metering cylinders, or cam operated decelerating valves, so that the valves rapidly reopen part way, as in the range 25 to 50 percent on a flow basis within $\frac{1}{2}$ second after the peak of the generator rotor forward swing.

How this could be accomplished would differ in detail only from what is shown in FIGS. 4 and 5.

Whereas in the case of both fossil fuel and nuclear steam turbines the desirability of making provision for fast partial reopening of intercept valves has been stressed it could also apply that providing for fast partial reopening of control valves could prove advantageous in situations where it might serve to limit requirements as to need for additional steam by-pass capability.

In the area of problems that could arise in application of fast turbine valving to nuclear steam electric installations the GE has cautioned that fast valving, even of the type that employs only momentary intercept valve closure, could give rise to difficulties in the way of malfunction of moisture separator reheater drain systems due to the mild form of MSR depressurization that takes place when intercept valves reopen after at first initially closing.

To the extent that such a problem exists it would tend to be intensified when control valves are rapidly closed.

However there is evidence which suggests that, with proper design of MSRs and their drain systems, rapid depressurization has not, and, in the case of fast valving will not cause a problem of consequence.

Test will be needed to clarify this point.

If, following tests, a problem remained that could not be readily solved one solution would be to provide to fully close both the turbine's control and intercept valves, and, after closure, rapidly open them both to a point at which the control valve has reached its preprogrammed new sustained position, and the intercept valve has reached an equally open position, on a flow basis, and providing thereafter to only slowly fully reopen the intercept valves under servo and/or rate of oil flow control, while in the case of PWR type reactors or at any rate in the case of Westinghouse PWRs this would not involve a need to provide added steam by-pass capability.

On the other hand it would represent a costly approach where BWR reactors were planned for use because it would require providing one hundred per cent by-pass capability.

However in the case of BWRs, and for that matter also in the case of PWRs, an alternate approach appears to be feasible, due to the fact that it is claimed that experience to date has shown that, presumably due to the cleanliness of the steam and its low discharge velocity, low pressure safety valves of nuclear installations have not leaked following discharge of steam, whether or not they are of the pilot operated type employing teflon O-rings which are widely employed in Westinghouse PWR installations, or of the spring loaded type used by GE in BWR and also in PWR installations.

To the extent that this claim can be relied on as a guide to the future, the point would apply that it is feasible to control turbine driving power in the period following the generator rotor first forward swing, by merely providing to suitably control intercept valve re-

opening (52) during the entire period during which steam generation within the reactor is being reduced, and rely on discharge of steam through low pressure spring loaded safety valves to limit rise in MSR pressure.

Moreover by providing to lift these valves in response to activation of electrically controlled air operated lift cylinders (51) with the use of pressure switches which could be preprogrammed to provide control only when fast valving has been involved, the valves could be employed as a way to hold MSR pressure constant during the entire fast valving process, thereby avoiding need for concern as to the behavior of MSR drain systems.

Furthermore it might also prove feasible to extend this concept to fossil fuel installations.

In the fossil fuel case the point would apply that experience has shown that reheat pressure safety valves are less likely to be damaged by discharge of steam than are high pressure types, due presumably to the lower velocity on steam discharge.

Also there is reason to believe that providing to lift safety valves with an air cylinder, rather than merely allowing them to lift on their own in response to increase in steam pressure, also can be expected to minimize damage effects.

Therefore, and especially if steps are taken so that the boiler, superheater and reheater are kept in a clean condition (63) the approach of providing for control of driving power in the period following the generator rotor first forward swing via control of rate of reopening could represent a workable procedure.

When it comes to how to regulate intercept valve reopening, there would remain the desirability of first rapidly opening the valves part way, and then proceeding more slowly.

When it comes to control of intercept valve position in the period following initial fast partial reopening, the point applies that for any type of steam-electric installation it is well within the skill of control system designers to provide, as with the aid of flow control devices, and/or servo systems which could be equipped with a time varying control input that could comprise a motor driven cam that varied the position of a core in a linear differential transformer, so as to effect preprogrammed processes of intercept valve reopening, such that following an initial rapid drop during the period of generator rotor first forward swing, turbine driving power would be restored to a new preprogrammed sustained value, which in the case of fossil fuel installations would preferably be selected to be somewhere in the range of 60 to 90 percent of full load value, but in the case of PWR and BWR nuclear installations, could cover a wider range, since thermal fatigue effects represent a minor factor in the life of nuclear turbines of these types, due to low value of steam temperature.

One point that has so far not been touched on relates to the fact that it is not unusual for steam driven boiler feed pumps to receive their steam from an extraction point of an intermediate pressure turbine, in which case the turbine steam supply from this source is downstream of the intercept valves and will be much reduced, if it does not momentarily disappear, when intercept valves are rapidly fully closed as an aspect of fast turbine valving.

This will result in a process of slowing down of the turbine which will operate to reduce rate of feed water

supply more rapidly than the preprogrammed extend of reduction of heat release within the steam generator, but the speed with which this occurs will be governed by the combined specific inertia of the turbine and pump, and, especially if intercept valves are rapidly reopened part way, it has so far appeared to experts in the design of fossil fuel steam generators, that the momentary slowing down that would be experienced would not be consequential as regards effect on the steam generator.

Moreover, in any case, turbines that, at over a predetermined load, accept steam from a point downstream of the intercept valve commonly are provided with means to accept steam either or both from the cold side of the reheaters or the high pressure steam header at light loads.

Normally separate steam chests are provided as a way to allow transfer to one or other of these steam sources and it could readily be provided, and may prove desirable, to effect transfer as a preprogrammed rapidly executed step that would be put into effect in response to a fast valving signal.

Similarly, if, in the case of nuclear units, in some cases, boiler feed pump turbines draw steam from a point downstream of the intercept valve, provision can be made to rapidly transfer to the main high pressure steam supply in response to a fast valving signal.

It is believed that the foregoing has served the purpose of showing how it is feasible to preprogram fast valving procedures, involving sustained step reductions in turbine driving power, which will well serve the purposes of power system designers when it comes to providing ways to minimize generation station first cost through avoiding need to install redundant circuit breakers, and also as a way to avoid need to construct redundant lines (36).

However to complete the picture it is necessary to provide so that processes of diversion of steam to atmosphere, or to the condenser, that need to be employed as a way to prevent discharge of steam through high pressure safety valves will be terminated without too long a delay.

Actually this is easy enough to accomplish by merely providing to simultaneously rapidly reduce heat release within, and feedwater supply to, the steam generator on a preprogrammed basis, with provision to temporarily override normally utilized feed back type control systems.

Also as matters stand providing this type of control is already well within the skill of designers of steam generator control systems, whether of types that are used in fossil fuel or nuclear steam generators. Thus systems for effecting coal fired steam generator runback to the extent of 50 percent, to the extent of 50 percent, accomplished in a matter of 30 seconds, (62), have been provided by steam generator producers, which speed of runback is accepted as fast enough to protect the reheater when turbine steam acceptance is reduced by 50 percent. Also faster runback is feasible with use of oil or gas as fuel, while provision for 25 percent runback of BWR nuclear units in a matter of 25 to 50 seconds, and of PWR units in 2 to 4 minutes, is typically feasible.

Based on the foregoing the essential feature of the present invention is viewed as comprising an explanation of how it is possible to provide in steamelectric units of U.S. type to respond to events that cause sud-

den at least momentary reduction of generator load by rapidly bring can, effect preprogrammed cases, processes directed to effecting sustained partial as well as momentary reduction of turbine driving power, in ways that are favorable to preservation of system stability, and with the use of techniques and equipment that are essentially already available, except to the extent that certain minor changes in equipment for controlling the rapid positioning of turbine valves represent features that are necessary to realization of full potentialities.

Moreover it is easily possible and will generally be useful to provide, within turbine and steam generator control system 39, a plurality of preprogrammed matched turbine and steam generator control processes, and to further provide so that, when an event occurs that sufficiently endangers system stability to require initiation of fast valving, generating station system responsive control system 33 will not only initiate it but will perform, in a preprogrammed way, the function of selecting for initiation one particular pair of control processes from among the available plurality of matched pairs, as for example by sending to control system 39 an input that causes initiation of a sustained reduction of driving power of 10 per cent when a fault occurs on line 1, but perhaps one of 20 percent if on line 2, and perhaps one of 40 percent if, as evaluated by what is shown in U.S. Pat. No. 3,657,552, it is expected that both lines will open due to delay in fault clearance, or if one line is already open and the other open, and perhaps also initiate a 40 per cent reduction when a fault occurs on line 3.

Also it is possible to provide as per what is shown in U.S. Pat. No. Re. 26,571, so that in case of unsuccessful reclosure on a faulted line, the initially selected pair of control processes are modified in a preprogrammed way, or so that the initially selected pair is modified if reclosure is successful.

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- Thus in its broadest scope the invention is characterized by the fact that it demonstrates how it is practicable to provide so as to allow effecting sustained partial reductions of turbine driving power, of selectively determined magnitude, effected fast enough to favorably affect system stability on second and following as well as first generator rotor forward swings, and in sufficient degree to escape loss of steady state stability, while avoiding adverse consequences, and do so at moderate or little cost.
- It will also be recognized by those who have read the writer's 1968 American Power Conference paper (33), as also from what is said in U.S. Pat. Re. No. b 26,571 (23), that this type of fast valving can prove especially useful when combined with provision for momentary application of braking load in that braking is well adapted to effecting marked improvement in generator rotor first swing stability, but can only be used to handle second swings at the expense of added cost and complexity.
- Based on the above, what I claim is:
1. In a steam-electric installation which incorporates a reheater, power operated relief valves located ahead of the high pressure turbine, which are so controlled as to open and discharge steam to atmosphere when pressure ahead of the valve or valves exceeds a preset value that is less than that at which the turbine's high pressure safety valves are set to open, and to reclose when pressure falls below a preset value which exceeds normal operating pressure ahead of the turbine, which installation is part of a power system which includes a plurality of prime mover driven generators, which generators are interconnected by a plurality of transmission circuits, the method of employing fast turbine

valving as a way to avoid development of system instability as a consequence of stability endangering events of a type adapted to cause the generator of the said installation to experience a sudden at least momentary reduction of load, which comprises the steps of,

1. providing within the turbine and steam generator control system, for response to a fast valving initiation signal input by bringing into effect preprogrammed jointly effected processes of,
 - a. intercept valve closure effected fast enough to have a favorable effect on generator rotor first swing stability, and control valve repositioning plus intercept valve reopening so effected as to cause turbine driving power subsequent to generator rotor first forward swing to hold below a preset value that is less than the driving power that applied prior to the event that brought about development of the signal,
 - b. runback of rate of steam production within the steam generator to a value that will cause termination of the discharge of steam through said power operated relief valves that will at first take place, with provision so that said runback is effected rapidly enough to avoid overheating of the reheater,
2. providing in a preprogrammed manner so that a fast valving signal is generated and transmitted as an input to the turbine and steam generator control system on the occurrence of certain types of events that endanger preservation of system stability.
2. The method of claim 1 wherein one of a plurality of pairs of coordinated preprogrammed processes of turbine and steam generator control will be selectively activated in dependence on the nature of the stability endangering event.
3. The method of claim 1 in which some but not all of the turbine's control valves are rapidly closed by valve actuator oil dumping.
4. The method of claim 1 in which half of the turbine's control valves are rapidly closed by valve actuator oil dumping.
5. The method of claim 1 in which one quarter of the turbine's control valves are rapidly closed by valve actuator oil dumping.
6. In a steam-electric installation incorporating a U.S. type once through boiler, one or more power operated valves that are arranged so that when opened they provide a path by which steam can by-pass from a point ahead of the turbine to the flash tank of said boiler, and from thence to the condenser, which valves are subject to the control of a control system which causes them to open when the pressure ahead of the valves exceeds a preset value which is less than that pressure that will cause discharge of steam through the turbine's high pressure safety valves, and are also so controlled as to close when pressure falls to a preset value that exceeds the normal operating pressure of the turbine, which installation is part of a power system which includes a plurality of prime mover driven generators, which generators are interconnected by a plurality of transmission circuits, the method of employing fast turbine valving as a way to avoid development of system instability as a consequence of stability endangering events of a type adapted to cause the generator of the said installation to experience a sudden at least momentary reduction of load, which comprises the steps of,

1. providing within the turbine and steam generator control system, for response to a fast valving initiation signal input by bringing into effect preprogrammed jointly effected processes of,
 - a. intercept valve closure effected fast enough to have a favorable effect on generator rotor first swing stability, and control valve repositioning plus intercept valve reopening so effected as to cause turbine driving power subsequent to generator rotor first forward swing to hold below a preset value that is less than the driving power that applied prior to the event that brought about development of the signal.
 - b. runback of rate of steam production within the steam generator to a value that will cause termination of discharge of steam through said steam by-pass valves with provision so that said runback is effected rapidly enough to avoid overheating of the reheater,
2. providing in a preprogrammed manner so that a fast valving signal is generated and transmitted as an input to the turbine and steam generator control system on the occurrence of certain types of events that endanger preservation of system stability.
7. The method of claim 6 wherein one of a plurality of pairs of coordinated preprogrammed processes of turbine and steam generator control will be selectively activated in dependence on the nature of the stability endangering event.
8. The method of claim 6 in which some but not all of the turbine's control valves are rapidly closed by valve actuator oil dumping.
9. The method of claim 6 in which half of the turbine's control valves are rapidly closed by valve actuator oil dumping.
10. The method of claim 6 in which one quarter of the turbine's control valves are rapidly closed by valve actuator oil dumping.
11. In a steam-electric installation which is part of a power system which includes a plurality of prime mover driven generators, which generators are interconnected by a plurality of transmission circuits, the method of employing fast turbine valving as a way to avoid development of system instability as a consequence of stability endangering events of a type adapted to cause the generator of the said installation to experience a sudden at least momentary reduction of load, which comprises the steps of,
 1. providing within the turbine's control system for response to a fast valving signal input by bringing into effect preprogrammed processes of,
 - a. at least partial closure of the turbine's intercept valves,
 - b. partial intercept valve reopening, to the extent of at least 25 percent brought to completion within $\frac{1}{2}$ second of termination of closure, and followed by more slowly effected full opening executed in a manner adapted to cause turbine driving power to hold below a preset value that is less than the driving power of the turbine at the instant of receipt of the said fast valving signal input,
 2. providing in a preprogrammed manner so that a fast valving signal is generated and transmitted as an input to the turbine and steam generator control system on the occurrence of certain types of events that endanger preservation of system stability.

12. The process of claim 11, in which intercept valves in step (1), are fully closed.

13. The process of claim 11 in which intercept valve reopening is initiated within 0.1 second of completion of the closing process.

14. The process of claim 11 in which partial intercept valve reopening carried out in step (2) is effected with oil supplied from accumulators, and is terminated by operation of valves of cam operated type, with cam position determined by valve stroke.

15. The process of claim 11 in which fast partial intercept valve reopening, carried out in step 2, is effected by the transfer to the cylinder of each of the

valve actuators, of a predetermined quantity of oil contained within a second cylinder.

16. The process of claim 11 in which control valves are repositioned in a manner adapted to bring into effect a preset sustained degree of partial closure, with provision so that said process of partial closure is accomplished rapidly enough, and to an extent sufficient, to prevent an increase in steam pressure ahead of the turbine's intercept valves that would suffice to cause discharge of steam through safety valves located ahead of said intercept valves.

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