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Main Considerations in Protection System Design for Geothermal Power Plant

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ABSTRACT

A proper protection system guarantees reliable and safe operation for a geothermal power plant. It is one of the most important factors during system engineering design and has to be carefully selected to avoid equipment damage due to failures. The process design should include the selection of a protection scheme as well as adequate main and auxiliary equipment and installation considerations. An adequate process design guarantees the reliable operation of protection systems and prevents damage to main equipment if an electrical or mechanical fault occurs in a Geothermal power plant. The information and data obtained are based on documents from Berlin power plant in El Salvador and Hellisheidi power plant in Iceland.

1. INTRODUCTION

Geothermal energy is one of the most important forms of renewable energy in the world and has several uses. In El Salvador, the main use for geothermal energy is power generation. There are two geothermal fields in El Salvador that have operating power plants: Ahuachapán and Berlin. Their combined installed capacity is 204.4 MW.

Protection systems are one of the most important parts in geothermal power plants and ensure a safe and reliable operation of the plant. Protection systems can be divided into two groups, electrical protections and mechanical protections. Electrical protection functions are identifying by device function number of each device installed in electrical equipment (IEEE, 1996).

In geothermal power plants, the electrical protection systems are almost the same than in other generation plants, such as hydroelectric or thermal generation plants, as the electrical components of the system are almost the same, with only minor differences or sizes.

The main difference between geothermal power plants and other kinds of generation plants is the generation process. Therefore, mechanical protections should have special interest for geothermal power plants. Mechanical protections include process protections, like pressure or temperatures measurements, and turbine-generator protections, like vibration or eccentricity.

The most important equipment taken into account in protection systems for a geothermal power plant in the present report are turbine and generator.

The protection system design considerations involve the electrical and mechanical protection functions for the most important equipment as well as other important factors which, although they may seem small, are equally important. These considerations include the most important technical characteristic for main and auxiliary equipment's selection, as well as installation considerations for reliable operation.

2. MAIN EQUIPMENT PROTECTION

2.1 Generator Protection Description

In power plants, generator is one of the most expensive equipment, therefore electrical faults must be identified and cleared in due time (Estevez, J., 2009). Synchronous generator protection requires considerations of harmful abnormal operation conditions more than any other power system element.

A simplified functionality of a synchronous generator can be described as follow: An electromagnetic field is developed by circulating direct current through loops of wire wound around stacks of magnetic steel laminations. These are called field poles, and they are mounted on the perimeter of the rotor. The rotor is attached to the turbine shaft, and rotates at a fixed speed. When the rotor turns, it causes the field poles (the electromagnets) to rotate and move past the conductors mounted in the stator. This, in turn, causes a voltage to be induced in the generator stator windings that are connected to the output terminals (Faraday's law of induction).

2.1.1 Generator grounding

It is common practice to ground all types of generators through some form of external impedance. The purpose of this grounding is to limit thermal and mechanical stresses and fault damage in the machine, to limit transient overvoltages during faults and to provide a means for detecting ground faults within the machine (IEEE, 1995).

The most common grounding method for large generators is the high resistance grounding. In this method, a distribution transformer is connected between the generator neutral and ground and a resistor is connected across the secondary. For a single phase to ground fault at the machine terminals, the primary fault current will be limited to a value in the range of about 3-25 A.

In some cases, the distribution transformer is omitted and a high value of resistance is connected directly between the generator neutral and ground. The resistor size is selected to limit ground-fault current to the range of 3 A to 25 A. While this method of grounding is commonly used in Europe, the physical size of the resistors, the required resistor insulation level, and the cost may preclude the use of this method.

2.1.2 Excitation system

The most common excitation system used in geothermal power plants is the alternator rectifier exciter and rotaring rectifiers (Brushless exciter). Figure 1 shows this excitation system that uses an alternator, but by mounting the DC field winding on the stator of the exciter and the AC armature winding on the rotor, all brushes and commutators have been eliminated. In this system, the AC armature of the exciter, the rotating three phase diode bridge rectifier, and the main field of the AC generator are all mounted on the same rotating shaft system. All electrical connections are made along or through the center of this shaft (IEEE, 1995).

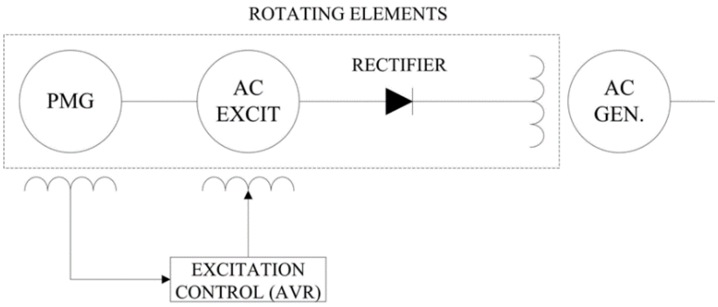

Figure 1: Brushless excitation system.

2.1.3 Generator stator thermal protection

Thermal protection for the generator stator winding (49) may be provided for generator overload. Most generators are supplied with a number of temperature sensors to monitor the stator winding temperature. These sensors are usually resistance temperature detectors (RTD) or thermocouples (TC). These sensors are used to continuously monitor the stator winding. The sensors may be connected for alarm purposes. In some applications, a current measurement is combined with a timing function to establish a thermal image of the stator winding temperature.

2.1.4. Generator stator fault protection

Generator faults can cause severe and costly damage to insulation, windings and the core; they can also produce severe mechanical torsional shock to shaft and couplings. Fault current can continue to flow for many seconds after the generator is tripped from the system and the field disconnected because of trapped flux within the machine, thereby increasing the amount of fault damage (IEEE, 1995).

The differential relay (87G) is commonly used as primary protection for phase fault on of generator stator windings. This function is mostly completely selective and can be used with very short tripping times. Differential relay will detect three phase fault, phase to phase fault and double phase to ground faults. Differential relays will not detect turn to turn faults in the same phase since there is no difference in the current entering and leaving the phase winding.

2.1.5. Ground fault protection

Differential relays will not provide ground fault protection on high impedance grounded machines where primary fault current levels are limited to 3A to 25 A. For high impedance grounding generators the most widely used protective scheme is a time delay overvoltage relay (59GN) connected across the grounding impedance to sense zero sequence voltage and a time overcurrent relay with instantaneous element (50/51GN) may be used as backup protection.

The conventional protection to detect stator ground fault in high impedance grounding systems only provide sensible protection to only about 95% of the stator. This is because the failure in the remaining 5% of the winding near the neutral will not cause enough residual voltage and current of 60 Hz to operate these relays.

For larger and more important machines, it is considered important to protect the entire generator stator winding with an additional ground fault protection system so as to cover 100% of the winding. There are several methods used as a means of detect faults near the stator neutral:

a) Third harmonic voltage at the neutral (27).
b) Third harmonic voltage at the terminals (59T).
c) Third harmonic differential between neutral and terminals (59D).
d) Sub-harmonic voltage signal injection and the neutral (59I)

2.1.6. Generator rotor field protection

The field circuit of a generator is an ungrounded system. A single ground fault will not generally affect the operation of a generator, however, if a second ground fault occurs, a portion of the field winding will be short-circuited, thereby producing unbalanced air gap fluxes in the machine. These unbalanced fluxes may cause rotor vibration that can quickly damage the machine; also, unbalanced rotor winding and rotor body temperatures caused by uneven rotor winding currents can cause similar damaging vibrations (IEEE, 1995).

The probability of the second ground occurring is greater than the first, since the first ground establishes a ground reference for voltages induced in the field by stator transients, thereby increasing the stress to ground at other points on the field winding. A voltage relay (64F) is used to detect overvoltage in the field winding produced by a ground fault.

On a brushless excitation system continuous monitoring for field ground is not possible with conventional field ground relays since the generator field connections are contained in the rotating element. One of the methods used is the addition of a pilot brush or brushes to gain access to the rotating field parts. The pilot brush can be periodically dropped to monitor the system. The ground check can be done automatically by a sequencing timer and control, or by the operator.

2.1.7. Generator loss of field

When a synchronous generator losses excitation it will over speed and operate as an induction generator. It will continue to supply some power to the system and it will receive its excitation from the system in the form of VAR. During this condition, the stator currents will be increased and, since the generator has lost synchronism, there can be high levels of current induced in the rotor that can cause dangerous overheating of the stator windings and the rotor within a very short time.

The most widely applied method for loss of field protection (40) is the use of distance relay to sense the variation of impedance as viewed from the generators terminals. Both the active and reactive part of the impedance must be evaluated.

2.1.8. Unbalanced currents

Generator unbalanced currents produce negative phase sequence components of current which induce a double frequency current in the surface of the rotor, the retaining rings, the slot wedges and in the field winding. These rotor currents can cause high and dangerous temperatures in a very short time. Negative sequence protection (46) consists of a time overcurrent relay which is responsive to negative sequence currents, protecting the machine before their specific limits are reached.

2.1.9. Loss of synchronism

When a generator loses synchronism, the resulting high peak currents and off-frequency operation causes winding stresses, pulsating torques, and mechanical resonances that are potentially damaging to the generator and turbine generator shaft (IEEE, 1995). The conventional method for loss of synchronism protection (78) is an impedance relay that analyzes the variation in apparent impedance as viewed at the terminals of system element.

2.1.10. Over excitation

Over excitation of a generator will occur whenever the ratio of the voltage to frequency (volts/ hertz) applied to the terminals of the equipment exceeds 1.05 per unit (pu) on generator base. When these volts/hertz (V/Hz) ratios are exceeded, saturation of the magnetic core of the generator can occur and stray flux can be induced in nonlaminated components which are not designed to carry flux and can also cause excessive interlaminar voltages between laminations at the ends of the core. The field current in the generator could also be excessive. This can cause severe overheating in the generator and eventual breakdown in insulation. Volts/Hz (over excitation) protection (24) is a function that measures both voltage magnitude and frequency over a broad range of frequency and determinate the Volts/Hz relation in the generator.

2.1.11. Motoring

Motoring of a generator (reverse power) occurs when the energy supply to the prime mover is cut off while the generator is still on line. When this occurs, the generator will act as a synchronous motor and drive the prime mover. Motoring causes many undesirable conditions, for example, in a steam turbine, the rotation of the turbine rotor and blades in a steam environment causes idling or windage losses. Windage loss energy is dissipated as heat. This can cause severe thermal stresses in the turbine parts (IEEE, 1995).

The reverse power protection (32) is a power relay set to look into the machine is therefore used on most units. Therefore, although listed along with generator protection functions, the reverse power protection is actually for protection of the steam turbine.

2.1.12. Overvoltage

Generator overvoltage may occur without necessarily exceeding the V/Hz limits of the machine. Where upon load rejection, the speed may increase and cause a proportional rise in voltage. Under this condition on a V/Hz basis, the over excitation may not be excessive but the sustained voltage magnitude may be above permissible limits. Protection for generator overvoltage is provided with an overvoltage relay (59).

2.1.13. Abnormal frequencies

Both the generator and the turbine are limited in the degree of abnormal frequency operation that can be tolerated. The turbine is usually considered to be more restrictive than the generator at reduced frequencies because of possible mechanical resonances in the many stages of turbine blades. Departure from rated speed will bring stimulus frequencies closer to one or more of the natural frequencies of the various blades and there will be an increase in vibratory stresses. As vibratory stresses increase, damage is accumulated that may lead to cracking of some parts of the blade structure.

Primary under frequency protection for steam turbine generators is provided by the implementation of automatic load shedding programs on the power system. These load shedding programs shall be designed so that for the maximum possible overload condition, sufficient load is shed to quickly restore system frequency to near normal. Backup protection for under frequency conditions shall be provided by the use of one under frequency relay (81) on each generator.

2.1.14. System Backup protection

It is common practice to provide protective relaying that will detect and operate for system faults external to the generator zone that are not cleared due to some failure of system protective equipment. This protection, generally referred to as system backup, is designed to detect uncleared phase and ground faults on the system.

Two types of relays are commonly used for system phase fault backup, a distance type of relay (21) or a voltage-controlled time overcurrent relay (51V). The choice of relay in any application is usually a function of the type of relaying used on the transmission system. In order to simplify coordination, the distance backup relay is used where distance relaying is used for transmission line protection, while the overcurrent type of backup relay is used where overcurrent relaying is used for line protection.

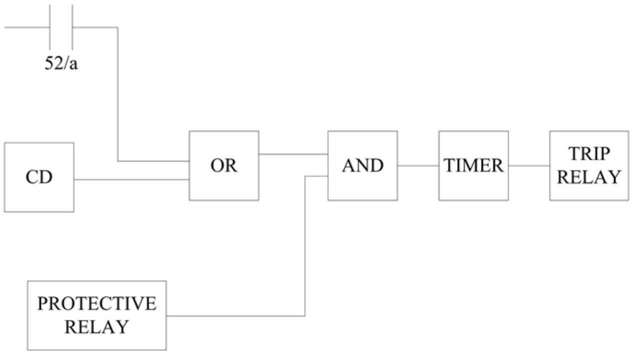

Figure 2: Breaker failure scheme.

2.1.15. Generator Breaker Failure Protection

When the protective relays detect an internal fault or an abnormal operating condition, they will attempt to trip the generator and at the same time initiate the breaker-failure timer. If a breaker does not clear the fault or abnormal condition in a specified time, the timer will trip the necessary breakers to remove the generator from the system.

Figure 2 shows that to initiate the breaker-failure timer, a protective relay must operate and a current detector or a breaker “a” switch must indicate that the breaker has failed to open. Breaker-failure schemes (50BF) are connected to energize a hand-reset lockout relay (86BF) which will trip the necessary backup breakers.

2.1.16. Voltage transformers

Loss of the voltage transformer (VT) signal can occur due to a number of causes. The most common reason is fuse failure. Loss of VT signal can cause misoperation/failure to operate of protective relays or generator voltage regulator run away leading to an overexcitation condition.

To eliminate the possibility of misoperations, it is common practice to apply a voltage balance relay (60) which compares the three-phase secondary voltages of two sets of VTs. If the fuses blow in one set of VTs, the resulting unbalance will cause the relay to operate. If a fuse blows, the relay will alarm and block possible incorrect tripping by protective relays whose performance may be affected by the change in potential.

2.1.17. Inadvertent energizing

Operating errors, breaker head flashovers, control circuit malfunctions or a combination of these causes have resulted in generators being accidently energized while off-line. When a generator is energized from the power system (three-phase source) it will accelerate like an induction motor. While the machine is accelerating, high currents induced into the rotor can cause significant damage in only a matter of seconds.

Dedicated protection schemes are necessary to protect the generator when it is off-line. Consideration shall be given to locating this protection in the switchyard where it is less likely to be disabled during generator maintenance. Common schemes used to detect inadvertent energizing are:

a) Directional overcurrent relays (67)
b) Frequency supervised overcurrent (50/81)
c) Distance relay scheme (21)
d) Voltage supervised overcurrent (50/27)
e) Auxiliary contacts scheme with overcurrent relays (50/41)

2.1.18. Protective arrangements and tripping modes

Table 1 show an example of the trip logic for protective devices on a geothermal power plant generator. The typical protective arrangement for a geothermal power plant generator is showed in Figure 3.

Device	Generator Breaker trip	Field breaker trip	Transfer Auxiliares	Turbine Trip	Alarm only
21 or 51V	X				
24	X	X	X		
27	X	X	X	X	
32	X	X	X	X	
40	X	X	X		
46	X				
49					X
50BF	X				
50/51 GN	X	X	X	X	
59GN	X	X	X	X	
60					X
64F	X	X			
67	X				
78	X				
81	X				
87G	X	X	X	X	

TABLE 1: Geothermal power plant generator trip scheme.

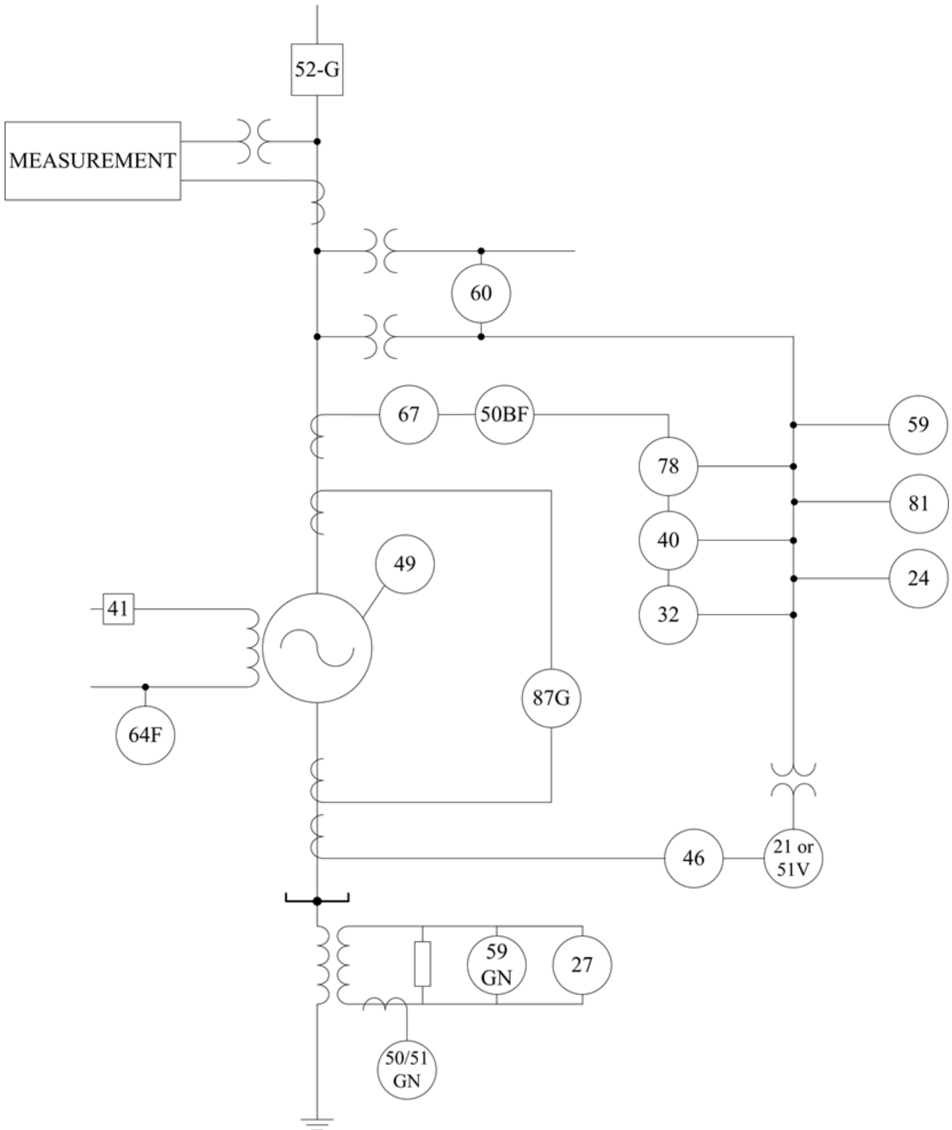

Figure 3: Typical Generator protection scheme.

2.4. Turbine-Generator mechanical protections

In geothermal power plants, the turbine has to be protected in all the events that can damage it. Part of the generator protection system described before provide any kind of protection to the turbine but there are other faults that need to be covered by an additional protection system.

Geothermal turbines require protections against mechanical faults that can be produced in the turbine components, in the geothermal generation process or in auxiliary equipment. Figure 4 shows a typical geothermal power plant P&ID with the most important components in the generation process.

2.4.1. Steam turbine inlet

The steam turbine inlet consists of following three main components:

a) *Steam collector*. Collects the steam from all geothermal wells in the field. This system has an overpressure protection that bypass the steam line to a silencer in case of pressure increases. When high pressure cannot be relieved by the silencer bypass, a trip signal is sent to the turbine.
b) *Demister*. Eliminates all the water that is contained in the steam. The most important protection is water level in the demister, monitored to prevent water from entering the turbine and damaging the blades. High level protection sends a trip signal to the turbine.
c) *Turbine control valves*. There are two control valves in series in the turbine inlet, one is for turbine stop that closes in case of turbine trip signals and the other one is for steam control inlet and is controlled by the governor system.

The turbine inlet has steam pressure and temperature measurements to ensure safe operating conditions for the turbine.

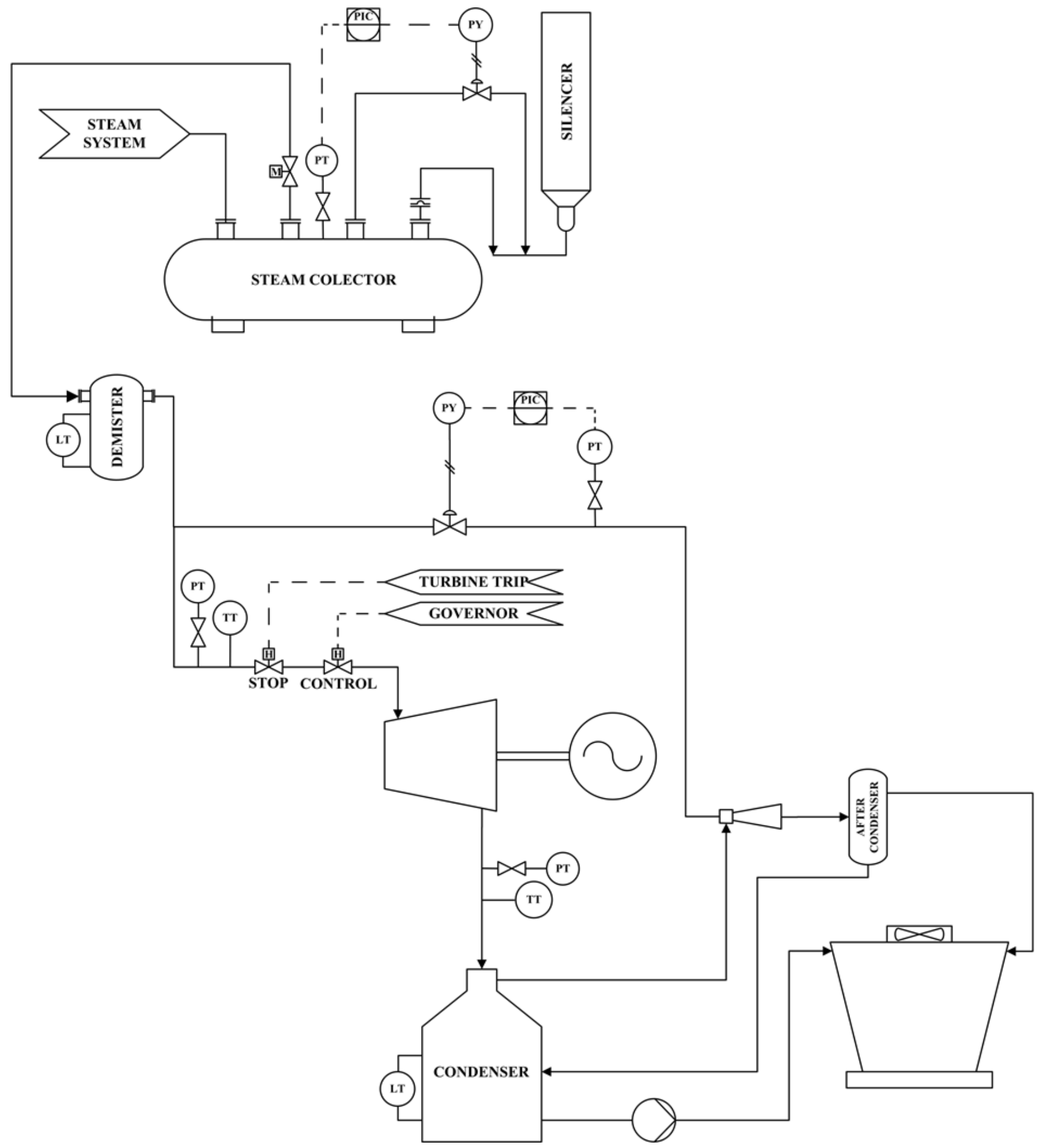

Figure 4: Geothermal power plant P&ID.

2.4.2. Turbine.

The turbine requires special protection equipment against mechanical faults. Turbine mechanical protections measurement include vibration, oil temperature, bearing metal temperature, steam seal pressure, overspeed, axial movement, eccentricity and differential expansion. Turbine mechanical variables are normally monitored and processed in a dedicated turbine supervisory system.

There are two auxiliary systems that are very important in turbine operation, the steam seal system and the oil system for control and lubrication. Pressure measurements guarantee normal operations conditions for both systems. For the oil system an oil level measurement in the oil tank is also necessary.

2.4.3. Condenser

The condenser system includes three main components that can affect the turbine operation:

a) *Turbine Exhaust*. Is the turbine outlet, the most important variables are the steam pressure and temperature. High steam pressure will increase turbine exhaust temperature and can cause serious damage in the last stage of blades.
b) *Condenser*. Makes the turbine more efficient, the most important variables are the water level measurement and the condenser pressure (vacuum).
c) *Gas extraction system*. Is in charge of the non-condensable gases extraction from the condenser. Non-condensable gases can cause turbine exhaust pressure increase. The most common gas extraction system for geothermal power plants are the steam-jet ejectors but vacuum pumps with electrical motors can also be used for this purpose.

Table 2 show the most important mechanical protection for a geothermal turbine-generator group and Figure 5 shows a schematic diagram with all the mechanicals protections.

Description	Location of measurement	Trip 1	Trip 2	Trip 3
Demister high level	Demister	X	X	X
Tur. exhaust high press.	Tur. exhaust	X	X	X
Tur. exhaust high temp.	Tur. exhaust	X	X	X
Cond. high level	Condenser	X	X	X
Tur bearings high temp.	All journal bearings	X	X	X
Gen bearings high temp.	All journal bearings	X	X	X
Oil bearing temp.	All bearings	X	X	X
Thrust bearing temp.	Thrust bearing on both sides	X	X	X
Tur. high eccentricity	Turbine Rotor	X	X	X
Tur. differential exp.	Turbine casing	X	X	X
Tur. rotor position	Turbine rotor	X	X	X
Tur. overspeed	Turbine rotor	X	X	X
Lube oil low pressure	Lube oil system	X	X	X
Control oil low press.	Control oil system	X	X	X
Turb-gen shaft vib.	All bearings in X and Y dir.	X	X	X

Trip 1: Turbine trip.
Trip 2: Field circuit breaker trip.
Trip 3: Generator Circuit breaker trip.

TABLE 2: Geothermal power plant turbine trip scheme.

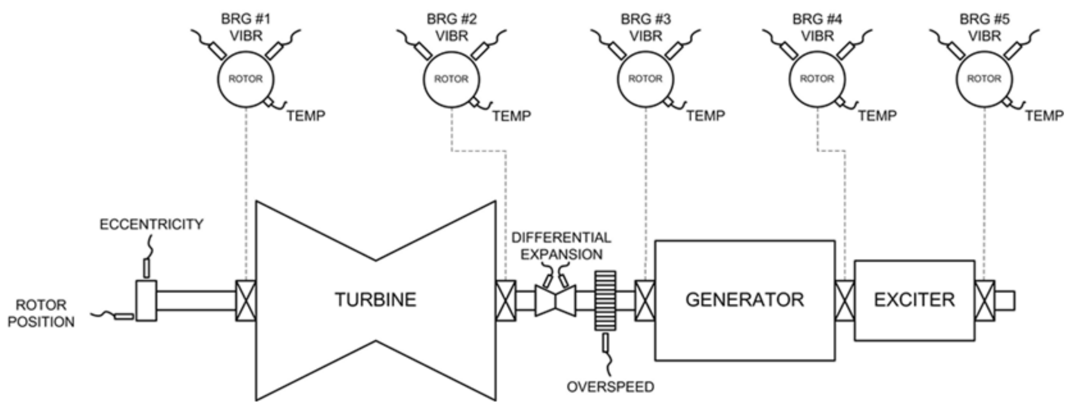

Figure 5: Turbine-generator mechanical protections.

3. PROTECTION RELAY SELECTION

3.1. General description

A relay is an electric device designed to respond to input conditions in a prescribed manner and, after specified conditions are met, to cause contact operation or similar abrupt change in associated electric control circuits (IEEE, 1989). Digital numeric relay is the new generation of protective relays, where many functions can be implemented by the microprocessor programming. That means that in one digital relay device, the implementation of one or all of these device functions can be performed.

The functions of protection are generally divided into two groups for redundancy purpose. Each group function is executed by a number of relay protections and is associated with different digital outputs. Relay redundancy is used for geothermal power plant protection, where two identical protection relays are employed and are connected to the same instrument transformer or two independent instrument transformers if applicable. Two different power supply sources are used for protection relay supply and for trip circuits. Circuit breakers often have two independent trip coils.

3.2. Protections relay specifications

Digital relay technology provides an economically viable alternative for electrical equipment protection. In addition, digital technology provides several other advantages, like improved performance, greater flexibility, reduced panel space and wiring, metering of various parameters, event reporting, fault data recording, remote communication, continuous self-checking and easy configuration (Estevez, J., 2009).

3.2.1. Function selection

Protection relays for geothermal power plants should be multifunction type and have to include the minimum function required for the equipment to be protected according to the description provided in this report and by international standards.

Protection relays should include current inputs, voltage inputs, digital inputs, contact outputs and optionally RTD inputs for thermal protection. The relay should have programming capacity to perform control and protection logics, define the function of digital inputs, and configure the contact outputs operation and timers functions (SEL, 2010).

The relay should include metering and monitoring functions to indicate different electrical variables and non-volatile memory for events records that could help for faults analysis. The relay should be capable of being serviced by Microsoft Windows based software with a friendly graphic interface.

For data access the relay shall provide a front panel LCD display and communication ports for data download, relay configuration and main SCADA communication.

3.2.2. Auxiliary inputs and outputs

Protection relays should include at least 6 digital inputs and 8 contact outputs. They shall be configured and defined by programming software for different functions and could be used as part of any control and protection logic program. Digital inputs should be opto-isolated contact inputs and contact outputs should be configurable as either normally open (a contact) or normally closed (b contact). Trip contacts should be configurable to be either latched (relay reset required) or non-latched (no resetting of the relay required).

The relay may optionally include RTD inputs, for thermal protection monitoring (49). The RTD types and location should be individually configurable by programming software.

3.2.3. Communication features

Communication port type and communication protocols available in protection relays should correspond to the most common applications used in industry. The particular ports and communication protocols selected for a determined application should be compatible with the SCADA system ports and communication protocols where the relay will be connected.

In case that the protections relay and the SCADA system communication protocols are not compatible, a communication protocol converter should be considered. In this case the relay communication protocol should be selected according to most common communication protocol converters used in the industry. The most primitive way of communication is using relay outputs that are wired to PLC inputs for signalization of relays operation.

4. INSTRUMENT TRANSFORMER SELECTION

4.1. Current Transformers (CT)

A CT transforms line current into values suitable for standard protective relays and isolates the relays from line voltages. A CT has two windings, designated as primary and secondary, which are insulated from each other. The secondary is wound on an iron core. The primary winding is connected in series with the circuit carrying the line current to be measured; and the secondary winding is connected to protective devices. The secondary winding supplies a current in direct proportion and at a fixed ratio to the primary current.

4.1.1. Rating of current transformers

The ratings of a current transformer shall include:

a) Basic impulse insulation level in terms of full-wave test voltage.
b) Nominal system voltage or maximum system voltage.
c) Frequency (in Hertz).

d) Rated primary and secondary currents.
e) Accuracy classes at standard burdens.
f) Continuous thermal current rating factor based on 30 °C average ambient air temperature.
g) Short-time mechanical current rating and short-time thermal current rating.

4.1.2. Standard burdens

Burden is the load connected to the secondary terminals and is expressed as volt-amperes and power factor at a specified value of current, total ohms impedance and power factor, or Ohms of the resistance and reactive components. Table 3 shows standard burdens for relaying CTs according to (IEEE, 1993). Burden selection for CTs shall consider cable and relay input impedance.

Burden designation	Resistance (Ω)	Inductance (mH)	Impedance (Ω)	Volt-amperes (at 5A)	Power Factor	Secondary terminal voltage
B-1	0.50	2.30	1.00	25.0	0.5	100
B-2	1.00	4.60	2.00	50.0	0.5	200
B-4	2.00	9.20	4.00	100.0	0.5	400
B-8	4.00	18.40	8.00	200.0	0.5	800

TABLE 3. Relaying current transformers burdens.

4.1.3. Accuracy

Protective-relay performance depends on the accuracy of the CTs not only at load currents, but also at all fault current levels. The CT accuracy at high overcurrent depends on the cross section of the iron core and the number of turns in the secondary winding. The greater the cross section of the iron core, the more flux can be developed before saturation. Saturation results in a rapid decrease in transformation accuracy. The greater the number of secondary turns, the less flux that is required to force the secondary current through the relay. This factor influences the burden the CT can carry without loss of accuracy.

According to (IEEE, 1993), relaying accuracy class is designated by use of one letter (C or T) and the classification number. C means that the leakage flux in the core of the transformer does not have an appreciable effect on the ratio, and T means that the leakage flux in the core of the transformer has an appreciable effect on the ratio. The classification number indicates the secondary terminal voltage that the transformer delivers to a standard burden at 20 times nominal secondary current without exceeding a 10% ratio correction. The ratio correction should not exceed 10% at any current from 1 to 20 times rated current at standard burden.

4.1.4. Nameplates

Nameplates should include, as a minimum, the following:

a) Manufacturer's name or trademark
b) Manufacturer's type
c) Manufacturer's serial number (SER)
d) Rated primary and secondary current
e) Nominal system voltage (NSV) or maximum system voltage (MSV) (None for bushing CTs)
f) Basic impulse insulation level (BIL kV) (None for bushing CTs)
g) Rated frequency (Hz)
h) Continuous thermal current rating factor (RF)
i) Accuracy rating

4.2. Voltage Transformers (VT)

A VT is basically a conventional transformer with primary and secondary windings on a common core. Standard VTs are single-phase units designed and constructed so that the secondary voltage maintains a fixed ratio with primary voltage. The required rated primary voltage of a VT is determined by the voltage of the system to which it is to be connected and by the way in which it is to be connected (e.g., line to line, line to neutral). Most VTs are designed to provide 120 V at the secondary terminals when nameplate-rated voltage is applied to the primary. In Europe, 110 V and 100 V are more common values for VT secondary voltages.

4.2.1. Rating of voltage transformers

The ratings of a voltage transformer shall include:

a) Basic impulse insulation level in terms of full-wave test voltage.
b) Rated primary voltage and ratio.
c) Frequency (in Hertz).
d) Accuracy ratings.
e) Thermal burden rating.

4.2.2. Standard burdens

Standard burdens for VTs with a secondary voltage of 120 V according to (IEEE 1993) are shown in Table 4.

Characteristics on standard burdens			Characteristics on 120 V basis			Characteristics on 69.3 V basis		
Designation	**VA**	**Power factor**	**R (Ω)**	**I (mH)**	**Z (Ω)**	**R (Ω)**	**I (mH)**	**Z (Ω)**
W	12.5	0.1	115.2	3.0400	1152	38.4	1.0100	384
X	25.0	0.7	403.2	1.0900	576	134.4	0.3649	192
M	35.0	0.2	82.3	1.0700	411	27.4	0.3560	137
Y	75.0	0.85	163.2	0.2680	192	54.4	0.0894	64
Z	200.0	0.85	61.2	0.1010	72	20.4	0.0335	24
ZZ	400.0	0.85	30.6	0.0503	36	10.2	0.0168	12

TABLE 3. Relaying voltage transformers burdens

4.2.3. Accuracy

Standard accuracy classifications of VTs range from 0.3 to 1.2, representing percent ratio corrections to obtain a true ratio. These accuracies are high enough so that any standard transformer is adequate for most industrial protective relaying purposes as long as it is applied within its open-air thermal and voltage limits.

4.2.4. Nameplates

Voltage transformers nameplates shall include, as a minimum, the following:

a) Manufacturer's name or trademark.
b) Manufacturer's type.
c) Manufacturer's serial number (SER), numerals only.
d) Rated voltage (PRI).
e) Ratio or ratios.
f) Basic impulse insulation level (BIL kV).
g) Rated frequency (in Hertz).
h) Thermal burden rating or ratings at ambient temperature or temperatures, in voltamperes or degrees Celsius.
i) Accuracy rating: maximum standard burden at which the accuracy rating is 0.3 class, as a minimum.

4.3. Safety considerations

Instrument transformers, as other transformers, transform the secondary impedance to the primary side. Therefore it is important for CTs that the secondary circuit never be opened, as this will be transformed to the primary side as very high impedance that the primary current is forced through. This will result in a dangerously high voltage across the CT secondary. Equally, the short circuiting of a VT secondary must be prevented with a proper fusing or fast mini circuit breaker (MCB). Otherwise, the primary side will be short circuited to ground through the VT primary, which may result in an explosion of the VT.

5. ELECTRICAL CONTROL SCHEMES

5.1. Substation control

An electrical substation is an important part of an electricity generation system where voltage is transformed from medium to high using transformers. Electric power may flow through several substations between generating plant and consumer, and may change voltage levels in several steps. Figure 4 shows a typical substation single line diagram.

The most important elements of an electrical substation are the disconnecting switches and circuit breakers. The disconnecting switches are used for no-load operation, like isolation of a circuit breaker for maintenance or as bypass equipment and cannot be operate with load. The circuit breakers are load operation equipment used for isolated parts of the electrical system in normal operation an in fault cases.

Substation control refers to all the conditions that permit the operation of a determinate element to the substation. These conditions make sure that the different elements are not operated under inappropriate conditions that can produce damage in any part of the generating plant. Each particular case requires a different control scheme but according to the single line diagram shown in Figure 4 the control scheme has to take in account the following conditions:

a) *Disconnecting switches* (89TA1 & 89TA2). This equipment normally has an opening circuit and a closing circuit operated by an electrical motor. The most important condition for the opening or closing of this equipment is that the circuit breaker 52-T has to be open.
b) *Earthing switch* (89ETA1). The earthing switch is part of one of the disconnecting switches and is used for grounding the bus for security during maintenance works. It can be operated manually or by electrical motor. The most important condition for the closing of this equipment is that the circuit breakers and disconnecting switches in both sides must be open.
c) *Circuit breakers* (52G). This equipment has one close circuit and two independent trip circuits. The most important conditions for the closing circuits are: disconnecting switches must be close, earthing switch has to be open and no trip conditions can be active. The trip conditions block the closing circuits by the lockout relays. The trip circuits should not have any conditions except the trip signals from the protection relays. The protection schemes divide the trips into two groups and each group is associated for one trip circuit.

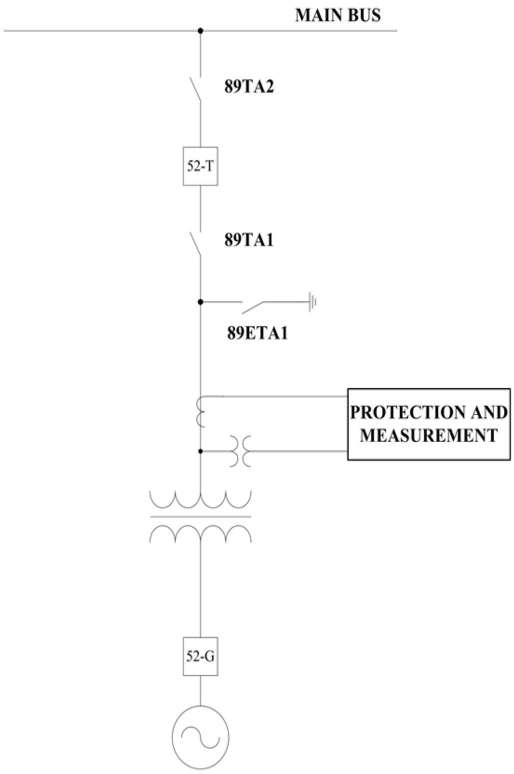

Figure 6: Typical substation single line diagram

5.2. Hardwire interlock

The safest protection schemes in geothermal power plants are the hardwired interlock, that consists of electrical connections between the different equipment to a protection system through hardwiring, avoiding the use of communication protocols or extra electronics equipment that could add an external fault to the system.

In this way, the protection schemes do not depend on external factors or equipment like PLC or communications protocols. This is an important consideration for the safe and reliable operation of protections systems. Hardwired interlock can be divided into two applications, trip applications hardwire interlock and control applications hardwire interlock.

5.2.1. Trip applications hardwire interlock

In protection systems, the only electronic equipment that should be present in a trip circuit is the protection relay. Protection relays receive the measurement signals from the instrument transformers and other mechanical protection measurement equipment like RTD for winding temperature measurement, then process the information and send the trip signal directly to the circuit breaker or through high speed auxiliary relays.

The electrical connections between the protection relay, instrument transformers, mechanical protections and circuit breaker trip circuits shall be made through hardwire to avoid external faults conditions caused by electronic devices or protocol communication faults. A marshalling box is normally used as an interface between the field equipment and the protection panels inside the power plant.

5.2.2. Control applications hardwire interlock

Electrical connections for control applications should be hardwired between the field equipment, like circuit breakers or disconnecting switches, and the auxiliary relays contacts used with protections relays. These hardwire connections should be made in the marshalling boxes and should avoid the use of PLC‘s for control or interlock functions.

For the substation control particular case described above, a marshalling box is normally located in the substation and all the auxiliary contacts and control circuits to the substation elements are connected on it. This marshalling box works as an interface between the field equipment and the control panels at the interior of the power plant. All the interlocks for the substation elements operation should be made in the marshalling box through hardwire to avoid external faults conditions that can be caused by electronic devices or protocol communication faults.

6. CONCLUSIONS

The protection system is one of the most important components of a geothermal power plant, for reliable and secure operation of all plant equipment. The correct design and selection of protections systems ensure that the power plant will be protected and any electrical or mechanical fault will not cause serious damage in the main equipment.

The protection scheme selection for the main equipment requires special attention to obtain high levels of availability in the operation of a geothermal power plant. An adequate scheme selection avoids unnecessary trips and minimizes loss conditions of the process, thus allowing the rapid return of the unit to the normal operation conditions.

During the startup of the protection systems design it is necessary to consider all the components for a complete protection system operation. These components shall include main equipment like protections relays or instrument transformers and auxiliary equipment like cable terminals or auxiliary relays to avoid delays into the construction and installation process.

Adequate protection system equipment selection avoids unnecessary trips or unsafe conditions during a fault and permits quick trips to eliminate the fault and minimize the damage in the protected equipment. Insufficient protection equipment selection or configuration can cause protection system failures in detecting a fault or causes an excessive delay in the fault detection. A delayed trip of the equipment or a no trip condition could damage the equipment.

Correct tripping action for a turbine-generator set in geothermal power plant requires an understanding of the technical characteristics of the steam turbine, the capacity of the system generator/turbine, the operation of the unit, and the process of geothermal energy conversion. An adequate trip selection avoids a complete power plant trip and permits rapid recovery of normal operation conditions.

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