Power Disturbance Management in Captive Power Plants

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Confidentiality Statement

The information in the document mentioned is not confidential and have been taken references from various sources as specified.

Abstract

Captive power plants have the dual objectives of ensuring uninterrupted power supply to their process plant and also to stay connected with the grid to ensure export of surplus power from their generating sets or import power from grid in case of shortfall.

Power disturbance, whether internal or external to the CPP, is a serious threat in the path of fulfillment of these objectives of the CPP.

With increased industrialization number of consumers of bulk power has increased many folds with a simultaneous increase in power disturbance.

So managing power disturbances has become a real challenge for CPPs.

Employment of suitable protection relays to deal with different types of internal disturbances and a suitable islanding system to deal with external disturbances are the main points of discussion of the subject.

Protection relays used in two different plants may be identical but relay settings of two different plants will vary depending upon the total generation, load, grid condition and

so many other factors.

The subject deals with the way of management of both internal and external disturbances by the CPPs with specific reference to the system adopted at NINL.

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Intended Readers

All steel plant employees

Description

Power System

A power system consists of the following sub systems

1. Power Generation system
2. Power Transmission system
3. Power Distribution system

The power system network can become unstable due to disturbance in any of the above subsystems.

Captive Power Plant

A captive power plant, as the name suggests, is where the power generated by the plant is consumed within that plant boundary only. But at present that definition has undergone slight modification. A power plant is called captive if major portion of the power generation is consumed within the plant boundary by internal consumers. So a captive power plant always coexists with a process plant. The process plant can be a steel plant, an aluminum plant, sugar plant, oil refinery etc. In all such cases power generation is not the prime job of these plants. Captive Power plant is just a service provider for the process plant.

Grid

The transmission network, which receives power from generating stations and supplies power to large utilities, is called grid. So grid is basically a HT distribution network.

Requirement of grid connection for CPPs

The basic purpose of any captive power plant is to supply reliable power to the process requirements. Captive power plants run in synchronized condition with grid supply for two purposes.

1. To give reliability to the power supply for the process by ensuring uninterrupted supply in the event of failure of the captive units or in the event of inadequacy of the captive generation to meet the process requirement.
2. To export the surplus power, if any, to grid to earn additional revenue.

Sale of power has become equally important in view of the permanent demand-supply gap and increased realization from sale of power after reforms in electricity sector.

So captive power plants have the dual responsibility of ensuring stable power supply for their process plants and to earn revenue from sale of power. But the responsibility of feeding power to the process has a priority over power export.

Disturbance

Disturbance in the power system is mainly variation in system voltage and frequency beyond permissible limit.

The captive power plants face disturbance in the power system both from external and internal sources.

Internal disturbance

Internal disturbance is disturbance in the power supply network, which is inside the plant where the CPP is located.

Typical power network of a CPP

Usually a CPP consists of more than one generating unit. The generating units generate power at 6.6 KV or 11 KV.

If generation and distribution inside the plant is at 6.6 KV, then voltage from the grid is stepped down to 6.6 KV and generating sets are synchronized at 6.6 KV level.

In case of bigger plants, distribution inside the plant is at 33 KV level. The power generated at 11 KV is stepped up to 33 KV by generator transformers. Power received from grid is stepped down to 33 KV. In this case synchronization is done at 33 KV level.

In side the plant there is extensive power distribution network supplying power to various shops. Depending upon the type of process, the number of shops in side the plant will increase.

The different possible reasons of power disturbance can be due to

1. fault in the generating system
2. fault in the distribution system

3. fault in the end use equipment

Faults in the generating system

Faults of the generating system can be divided in to 3 categories.: faults in the generator, faults in the generator transformer and faults in the turbine.

Faults in the generator are

a. Stator over current
b. Voltage restrained over current
c. Stator earth faults(95 % and 100 %)
d. Stator Differential current
e. Over load
f. Over voltage
g. Unbalanced loading/negative sequence
h. Over fluxing
i. Rotor earth faults
j. Loss of excitation
k. Loss of synchronism or out of step
l. Failure of prime mover

Faults of the generating transformer are

a. Over current
b. Earth fault
c. High oil / winding temperature
d. Transformer differential current
e. Other transformer faults like buchholtz, PRV

Faults of the turbine are

a. Lubrication oil failure
b. Over speed
c. High vibration
d. Low vacuum
m. Difference in expansion between rotating and stationary parts
e. High bearing temperature
f. High axial displacement

Tripping of the turbine due to any of the above reason will lead to tripping of the generator on failure of prime mover protection of generator.

All the faults of the generator are classified in to 3 types of faults: class A, B & C.

Class – A faults are electrical faults, which will require tripping of both generator and turbine.

Class - B faults are faults of the turbine and the generator will trip as a result of turbine trip.

Class - C faults are electrical faults for which only the generator breaker will be opened but turbine will be kept running.

When the generator is running in synchronism with grid, out of the above faults only over current and earth fault type of faults have a potential to create immediate disturbance in the power system. All other faults are going to affect that particular generator only.

Since the CPP is connected with grid, additional power requirement because of tripping of a running generator will be supplemented by grid. So the power system will not experience any disturbance in voltage or frequency. However tripping of the generator will affect the export/import scenario of the plant ability of the CPP to run in isolation.

Management of disturbance in the generating system is a two fold approach

a. proactive measures to prevent generating system failure
b. Fast removal of faulty generating system from the network to minimize disturbance.

The generator and turbine are monitored by online systems for temperature, vibration, axial displacement, lubrication etc. The loading of the turbine is regulated to avoid too fast loading and unloading to avoid thermal stress on turbine.

Fast acting numerical relays are provided to trip the generating unit in case of any of these faults being sensed by the system. Generator protection consists of composite generator protection relay, composite transformer protection relay, separate protection relays for stator earth fault and rotor earth fault relay

Faults in the distribution system

Faults in the distribution system can be faults in the supply feeders or faults in the distribution transformers. They will be mainly of over current and earth fault type and other faults of the transformer. To minimize disturbance to the power system fast acting over current, earth fault and transformer protection relays are provided to clear such type of faults.

Fault in the end use equipment

End use equipment in the industry is mainly motors to drive various type of equipment like pumps, fans etc. The different possible faults of a motor are

a. Over load
b. Long starting time
c. Locked rotor
d. Short circuit
e. Earth fault
f. High winding temperature
g. Negative sequence current
h. Under voltage
i. High vibration
j. Out-of-step (for synchronous motors)

Fast acting composite numerical motor protection relays are provided to detect each of the faults at an early stage and isolate the faulty equipment from the system to protect the power system from serious damage. It is to be noted that a motor protection relay is not always to protect the motor, it is more required to isolate a faulty motor in order to protect the power system form possible disturbance.

Time grading of relays

Faults of over current and earth fault in nature create a disturbance in the power supply network. This disturbance is felt all over the network.

Protection relays provided for different equipment are programmed in such a manner to isolate a faulty system in the quickest possible time with minimum possible power interruption for process equipments. Fast fault clearance and selective tripping is achieved by proper current and time gradation of the protection relays.

External disturbance

External disturbance is experienced because of a disturbance in the HT transmission and distribution system i.e the grid.

Disturbance in the grid supply originates from the following reasons

1. Earth fault/phase fault in the system- it will create dip in system voltage
2. Sudden outage of a generating unit- it will result in dip in frequency
3. Sudden outage of a large load- it will result in increase in system frequency.
4. Power failure in the grid(momentary or longer duration)

A grid is said to be disturbed when :

a) there is an under voltage (U/V)
b) there is over voltage (O/V)
c) there is a rapid fall or rise in voltage(+ dv/dt or –dv/dt)

d) there is under frequency (U/F)
e) there is over frequency (O/F)
f) there is a rapid fall or rise in frequency (+df/dt or –df/dt)
g) there is a power failure in the grid

Grid also deploys protection relays for fast fault clearance with selective tripping of supply networks. However the captive power plants, which have a greater responsibility to protect their process plants from power disturbance, cannot wait till such time for the grid to clear the disturbance. If the disturbance persists for a longer period or increases in intensity it will cause serious damage to process equipment and to process.
To save their process and process equipment from likely damage due to power disturbance from grid side, captive power plants resorts to islanding.

Islanding

Islanding is the process of disconnection of the captive power plant from the grid and running in isolation.

Need of Islanding

As the grid is connected to a number of generating stations and consumption centers at the same time, because of continuous variations in generating condition and consumption pattern, it always fluctuates with respect to voltage and frequency. Equipments of all the plants are subjected to this variation in voltage and frequency. Disturbed condition of the grid create additional stress on equipments and can destabilize the electrical system.

Islanding is required for power system stability. Islanding is required by both the grid and CPP owner. Islanding helps both the Grid as well as the CPP owner in maintaining power system stability.

Benefits to Grid

The Grid normally does not want an additional independent power source in their grid network, when the grid is disturbed. Since the power source is not in their control, it will complicate grid's methods of dealing with the disturbed grid. While the grid is in the process of solving the grid disturbance, they do not like to have another power source which they do not control and which may add to the disturbance. Once the non grid power source is disconnected from the grid, it becomes easier for them to locate the source of disturbance and rectify the same. The main idea is that grid eliminates the possibility of the CPP feeding the disturbance. Hence the availability of the Grid islanding scheme in the CPP owner's premises is a precondition for allowing the CPP to be connected to grid.

Benefits to CPP owner:

It is strongly advisable to disconnect the captive power plant from the grid, when the grid is disturbed. The main reason is that the generating sets may get spoilt due to grid disturbances resulting in heavy repair costs and shut downs. Since grid is the infinite source, the voltage and frequency of CPP is dictated by grid. Adverse voltage and frequency condition of the grid will affect the process equipment and hence process of the CPP.

It is also required that in the event of grid failure, the CPP must be disconnected from the grid. This is to prevent collapse of the CPP as it will try to feed power to the entire grid. Also when power comes back in to the grid, it will not be in synchronism with the CPP power. If not disconnected it will cause very serious damage to the power system equipments of the CPP. Hence the CPP is required to put an islanding scheme when the CPP has to operate in parallel with the grid.

Grid Islanding Scheme

Grid Islanding scheme is a set of protective relays, connected at the incomer bus – these relays will sense a disturbance in the grid and give a trip command to the incomer breaker whenever the grid disturbance exceeds a set limit. By opening the incomer breaker, the plant is isolated from the grid. The plant as well as the generating sets are disconnected from the disturbed grid by the grid islanding scheme.

Islanding Criteria

The following are different criteria for islanding.

Under voltage and over voltage (U<, U>)

Islanding due to grid under voltage and over voltage is required to minimize the risk to equipments of the CPP. Loaded motors, for instance, need a higher current when the mains voltage is reduced and this can result in thermal overload or even stalling The grid voltage is monitored for both under voltage and over voltage conditions at the point of islanding. When voltage changes beyond the set limit islanding of the CPP is effected. Islanding because of under voltage and over voltage is always effected with a time delay to avoid unwanted islanding. For example, start of a motor can also cause a short term voltage drop which has to be permissible. A suitable time delay will help in filtering out nuisance islanding.

Rate of change of voltage

Apart from under voltage and over voltage, the rate of change of voltage is also monitored for effecting an islanding. Unlike the criteria of under voltage and over voltage where the process equipment are subjected to certain amount of adverse voltage conditions, monitoring the rate of change of voltage for islanding helps in avoiding the adverse voltage condition being experienced by the process equipment.

Voltage unbalance

A voltage unbalance relay monitors the symmetry of voltage vectors in three-phase systems. Resolving of a vector system into symmetrical components

- Positive phase-sequence system U1
- Negative-phase sequence system U2
- Zero-phase sequence system U0

is a method commonly used.

When a short circuit occurs in one phase or two phases, the voltage vectors of the faulty phases deviate from their normal values. This effect is reflected in rise of the amplitude of the negative phase sequence system and in voltage drop of the positive phase-sequence system. The amplitude of the zero-phase sequence system is a quantity for displacement of the voltage vector star point from its normal position. This is used as a criteria for islanding.

Power flow

With this protection method the direction of the electrical energy flow at the islanding point is monitored. But this criteria for islanding is employed when the CPP always imports power . This criteria can not be employed if the CPP is exporting power to the grid.

If the CPP is in export mode, a low forward power relay is used to detect the grid failure. However since CPP is also likely to import power during shortfall in generation, low forward power cannot be a foolproof method of detecting a grid failure to effect an islanding.

So for plants with constant energy export or with changing energy flow direction power monitoring relays are used in combination with other relays.

Over frequency/under frequency (f> , f<)

The frequency of the grid network will increase if the total power of generating stations connected to the grid is more than the load connected to the grid and vice versa.The grid is considered to be the infinite bus. The CPP which has a very small power generation as compared to the grid can not change the frequency of the grid.Since the CPP runs in synchronism with the grid, the frequency of the power generation of the CPP units will follow that of the grid.

So when frequency of the network changes beyond certain set limit, it indicates that there is mismatch between demand and supply of power. Failure of the mains supply can also lead to such a situation. Since this is a potential disturbed condition of the grid, this under frequency/over frequency criteria is used to effect an islanding of the CPP.

The criteria of under frequency and over frequency are always used with a time delay to avoid nuisance tripping.

Rate of change of frequency (df / dt)

Since frequency of the grid varies almost continuously between set limits, effecting islanding on the basis of under frequency/over frequency may lead to either delayed islanding or too frequent islanding both of which are not intended by the CPP. So rate of change of frequency is effectively used to effect reliable islanding. Rate of change of frequency(df/dt) is always used with actual frequency (f) to get the desired result.

Vector surge

Synchronous generators are generally operated in parallel with the grid utility. This ensures greater reliability and enables the generator to export power to the grid. In this condition, there is a chance, of a momentary interruption of the grid supply which may result for a few milliseconds. Such temporary interruptions can be caused due to mal-operation of the circuit breakers on the grid transformer side.

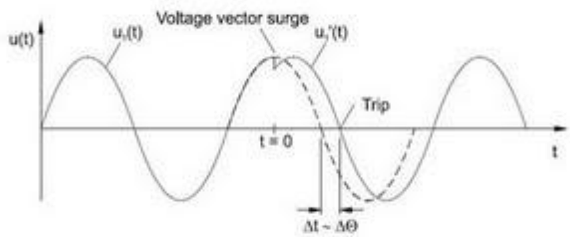
For a synchronous generator, running in parallel with the grid utility, such a temporary interruption and restoration of the supply can be dangerous. As the restoration of the supply can be asynchronous i.e. the generator and the grid are now not in a synchronised condition. This can lead to the consequences of wrong synchronization such as damage to the generator or the prime mover.

During the period of grid failure, the rotor displacement angle which is the angle between the vector of the mains voltage V and synchronous electro-motive force, changes.

The vector surge relay functions by monitoring the rate of change of the rotor displacement angle of the generator. During parallel operation there is an angular difference between the terminal phase voltage (V) and the internal synchronous voltage of the generator (E). This is due to the fact that the generator rotor is magnetically coupled to the generator stator and is forced to rotate at the grid frequency. The angle between the vector of the mains voltage V and synchronous electro-motive force is known as the rotor displacement angle.

This angle is constantly varying and is dependent on the torque produced by the generator rotor. In the case of the grid failure, there is sudden change in the rotor displacement angle.

This causes a surge in the generator voltage shown in the figure. The relay works by monitoring the time taken between the zero-crossings in the waveform. Under normal operation the time interval between two consecutive zero-crossings is almost constant.



During the grid failure, the vector surge which occurs causes a delay in the zero-crossing. This delay is detected by a highly sensitive timer inside the relay and the relay operates. The relays are usually set to operate for a change in the rotor displacement angle of 0 to 20 degrees.

Combined criteria

In order to clearly distinguish between the different kind of failures in a network, it is useful to logically combine several of the before mentioned criteria. Combined criteria improve the reliability of the islanding.

Over current and under voltage (I>& U<)

A combination consisting of over current and under voltage always signals a short circuit or excessive load at the output supervised. In many power export applications an over current relay with inverse current-time characteristic is being used. The characteristic the current relay is based on is defined by the under voltage relay. If, for instance, the mains voltage drops below 60 % UN at a coincidental I> pick up, a close short circuit is assumed and the relay operated with a faster trip characteristic. In cases where the voltage does not drop below the set value, the short circuit is regarded as having occurred further away and a slower characteristic is used for over current trip. Selective shutdown can then be realized by a relay closer to the actual fault. As it is the case with all current-time characteristics, this method is very suitable to disconnect many parallel operating generators selectively from the mains, preventing the entire network to be without voltage at once. This method cannot be used for quick islanding at automatic reclosing because it is too slow due to the trip delay of the current protection. The delay time of the over current detection should not be set too short because there would be a risk of tripping during switching operations and transients in the mains.

Directional overcurrent (I> & U<)

By a pure reverse power supervision the operating modes possible are restricted (e.g.only supply into the public grid) because the current is only allowed to flow in one direction. If this restriction is not acceptable for a certain application, islanding can be realized by the combination of current direction and under voltage. To achieve this, the tripping contacts of both relays are connected in series (interlinked to AND). During healthy operation the current at the mains coupling point is permitted to flow in both directions. The directional current relay is set to the effect to trip in direction of grid if short circuit type currents arise. The under voltage relay trips if the mains voltage drops under a set threshold. If short circuits occur in the grid, both relays respond at the same time and the coupling switch is opened. If short circuits occur in the own system, the current relay does not trip. The necessary disconnections in the own system are selectively carried out by other protection elements. This method makes prompt islanding of the CPP possible. Energy is permitted to flow in both directions. This method is not suitable for islanding during mains failures with an insignificant drop of the voltage.

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Requirement of the islanding scheme

From the different criteria described above, a reliable islanding scheme should have all of the following features for islanding

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Adjustable multistage under frequency with adjustable time delay

Adjustable multistage over frequency with adjustable time delay

Adjustable rate of change of frequency (df/dt) along with under and over frequency

Adjustable under voltage with adjustable time delay

Adjustable over voltage with adjustable time delay

Adjustable rate of change of voltage (dv/dt) along with under and over voltage

Voltage vector shift or vector surge principle

Directional over current and earth fault for faults outside Power Plant zone

Relays to detect Grid disturbances

Previously used electromechanical relays for over voltage and under voltage, earth fault etc have given way to more reliable and user friendly numerical relays. Unlike electromechanical relays the over voltage and under voltage condition of the grid are sensed by single UV/OV relay.

A separate numerical relay is used for sensing rate of change of voltage(dv/dt).

The parameters like frequency, df/dt are monitored by numerical relays .

Numerical relays, with capability to perform mathematical algorithms and to offer very high accuracy & resolution (settings in terms of 0.01 Hz) are normally used to detect df/dt.

A vector surge relay is useful to detect grid failure condition and also it gives fast response to grid disturbance. This is an extremely fast acting relay with an operating time of less than 300ms from relay operation to breaker opening.

Grid faults are detected by directional Over current + Directional E/F relays.

Typical relay settings for the islanding scheme

O/V & U/V

O/V – 110% , 1sec.

U/V – 85%, 0.5sec.

Over frequency/Under Frequency

U/F – 47.6Hz, 5sec. & 47.5Hz, 0.5sec

O/F – 52.5Hz, 1sec.

Vector Surge Relays

Vector Surge ($\Delta\theta$)– 6 deg.

Rate of change of frequency -

df/dt – 48Hz & 1Hz/ sec. and 52Hz & 1Hz/ sec.

Rate of change of Voltage -

dv/dt – 75Vs/sec.

POST ISLANDING REQUIREMENTS

Apart from effecting an islanding i.e opening of the incomer breaker of grid, a number of changes are required to be done in the control system of the CPP to make the islanding stable.

The following need to be done for the islanding scheme to become successful.

a. Immediately after islanding, the islanding signal is given to the governor of the turbine. This is required to change the governor from load control (PI control) to speed control (PD control) mode. Speed control mode is faster than load control mode. The governor of the generator is made fast acting to take care of a situation where generation at the time of islanding is more than the connected load after islanding takes place.

   This is also required for the governor of the TG to respond to any load change during the islanding condition.

b. Though tripping of a generator due to fault does not create a major disturbance in the power system during synchronized operation, it seriously handicaps the ability of the CPP to run in islanding mode. If the islanding load of the CPP is more than the available generation of the CPP, then load shedding is to be done to bring the islanding load lower than the generating capacity. A fast acting load management scheme is put in place for stable islanding to take place. The excess load is switched off by a suitable load-shedding scheme to make the islanding of the generator stable. The frequency of the power system is monitored to shed loads in staggered manner.

c. In case of severe voltage disturbance the drives of the captive power plant also trip leading to unstable condition after islanding. Suitable schemes are put in place to take care of such type situation.

d. Usually the Automatic Voltage Regulators of the generators operate in power factor control mode. After islanding, this is to be made off and the MVAR generation is matched with the requirement of the plant. Otherwise it will lead to under voltage/over voltage condition.

During the period of islanding, CPPs have to put a strict restriction on starting of bigger drives as that can destabilize the power system network leading to total power failure.