ELECTRICAL ASPECTS OF ELECTRICAL GENERATION FROM TIDAL CURRENTS

Generators

A number of options exist as to generators but the primary ones are likely to be either induction generators of synchronous machines. Induction generators on their own will provide a cheaper generator than a synchronous machine. However the use of synchronous machines will permit the control of power factor and give a higher efficiency for lower-speed machines. A key feature is the size and hence cost of the generator, which will increase with reduced speed and the cost of the gearbox, which will increase with increasing gear ratio.

Control Schemes

Under particular stream velocities it is possible to select a best speed for operation and this can be achieved if some form of control to be included. Basically control will be expensive and can only be considered when there is a certain synergy in the system. Thus it is possible to offer a d.c. link system to land with a converter on the shore and another one on each node in the stream farm. In addition to allowing and improvements in turbine performance and starting and reversing arrangements, this can also result in significant savings with regard to the cost of circuit breaker upgrading on the land. Since the semiconductor systems will offer the possibility of extremely rapid shut down, the fault source from the turbine site can be controlled and the power levels in the breakers in the grid system can remain unchanged. In addition, rapid power flow changes can be obtained from the turbines that can assist in controlling the stability of the system. Systems such as this will have to handle the total power flow and will therefore be costly, only being justified by savings in other cost centres.

Electrical Links

For the distances being considered for offshore stream power, the links could easily be a.c. and the system linked directly into the grid system. Links of this type will add to the system fault current, but have the great advantage of not introducing higher frequency harmonics.

Choice of a.c./d.c. Voltage Magnitude

For the distances and powers being considered a.c. transmission will be viable. The choice of a.c. or d.c. transmission will therefore depend on the economics of the situation and the control scheme used in the generators associated with the turbines. Briefly, d.c. will be more expensive but may save costs in the protection associated with the wind farm. Voltage rating of the link can be chosen to suit. For the powers being considered 11 to 38 kV could be considered as a realistic option, the choice depending on the distance of the farm from the shore and the power levels being transmitted.

For a.c. systems the generators being considered are typically of 250 to 750 kW and this would suggest a maximum generation voltage of 1.1 kV. This voltage would generally not be high enough for direct connection to shore and a transformer would be installed at node points where the cable to shore is connected. If the voltage is transformed to a level compatible with the connection on shore then no further transformer will be required. This will depend on the distance to shore, remembering that the cost of survey and cable installation is a significant fraction of the total cost.

There are two likely configurations for turbines in a stream farm. In some instances the stream will be narrow and the configuration could be as in Figure A1. In other cases the stream will be wide and the configuration as in A2.

Each unit, which is considered to consist of two turbines, may have three different configurations. Type N shown in Figure A3 will be a node where the HV cable is connected and will incorporate a transformer and the appropriate switchgear to ensure that any faulty component can be isolated with minimum disruption to the system. Type T, which is a through connection for the LV circuit is shown in Figure A4 and Type E, shown in A5, simply incorporates the generators and a direct connection to a node.

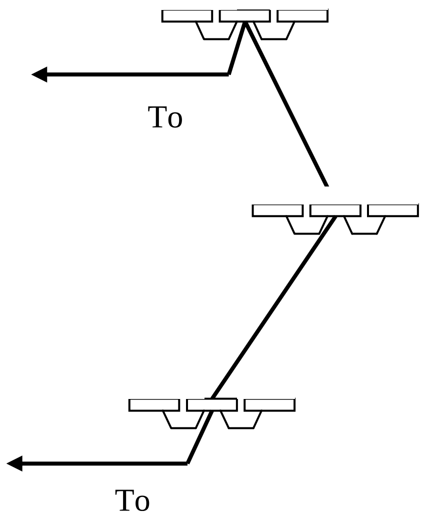
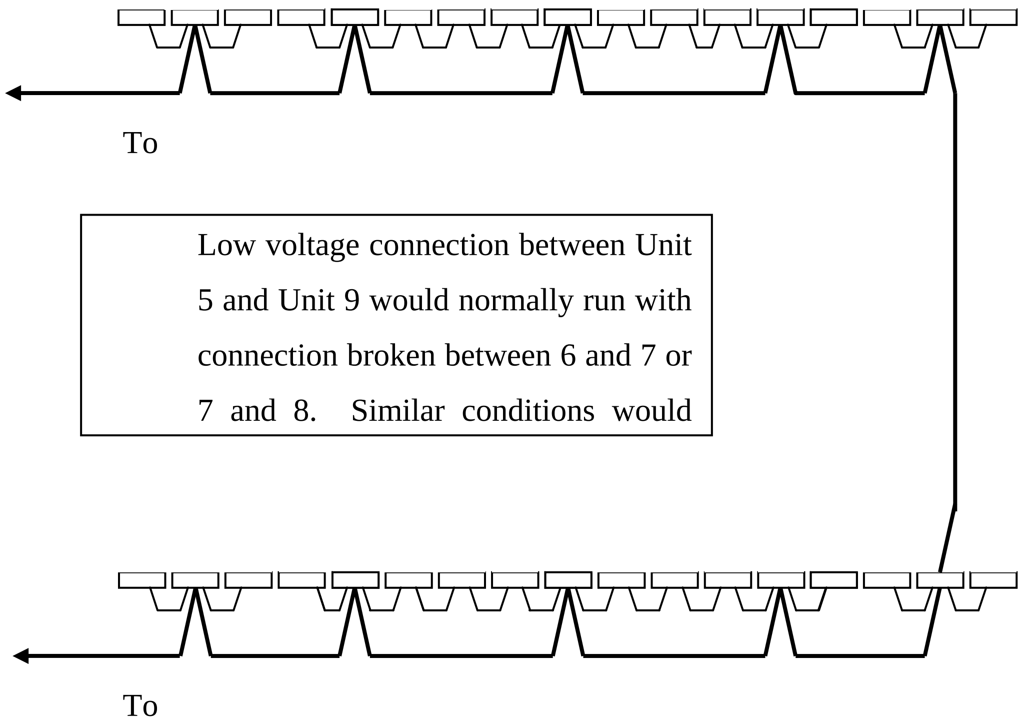


Figure A 1 Configuration with narrow stream



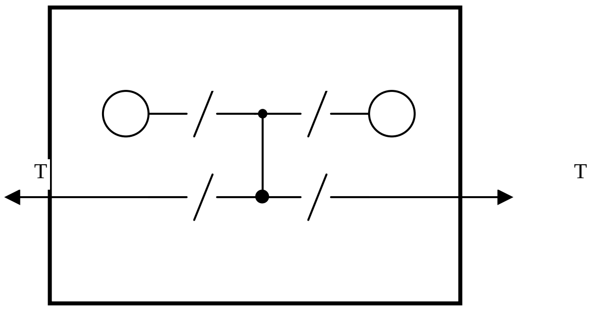


Figure A 3 Type T unit configuration

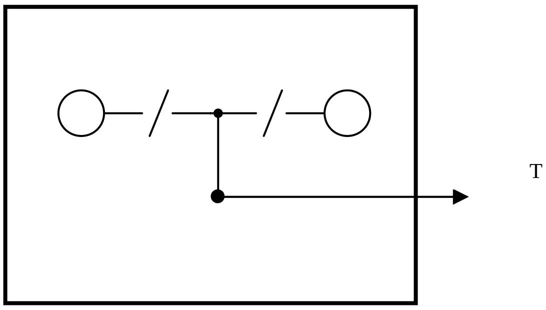


Figure A 4 Type E unit configuration

Steam farm to shore

The use of a cable from the stream farm to shore will require the cable to be buried on the seabed. This is for protection against trawlers and dragging anchors. To achieve this the cables will be laid in a trench, which will fill naturally with debris.

Shore to grid connection point

The connection on shore is likely to continue for some distance by cable, say 1 km, and ultimately by overhead line if any significant distance is to be covered. In view of the problem of making connections in the vicinity of load centres it may be necessary to interface with the grid in a more rural location.

Impact on power flows in network

Any supply network will be designed to handle power flows to the major loads in such a way that the voltage remains within an acceptable tolerance and that there will be a back-up route if one element in the network fails.

Loads will demand real power but will, in general, also demand reactive power. The latter has a significant impact on the voltage drops in the network, especially at high voltages. Thus it is not uncommon to have reactive loads that can be connected during periods of light load to hold the voltage at an acceptable level. Real power flow through a network results in a phase shift that is largely unnoticed by the customer. The reactive power will result in additional current and hence losses in the networks but not in the transfer of any useful power from generator to factory.

In the case of the potential stream farms that have been examined the power levels have been relatively low but tend in many cases to be in remote areas. The MV network in the RoI is being upgraded and the new system will be based on 20 or 38 kV lines and the 38 kV lines should prove adequate for connections.

The key issue in any power network is that the power supplied must equal the power delivered, the system being largely customer driven. Thus, if a load increases, an equivalent amount of power must be generated otherwise the frequency of the system will fall. Power levels from tidal stream sources are unlikely to cause problems in power balance and difficulties are more likely to occur with voltage variation in the MV lines. To ensure adequate voltage control reactive compensation could be necessary. This will depend on the line rating and the power flow and could be achieved by a reactive compensator at the point of common coupling.

Stream Farm Generation

The control of the stream farm would be entirely automatic. The output from the farm would be dependent on the tidal flow with four periods of generation each day. These are easily predicted and the output from the farm will be limited so that constant power will be available for the majority of the time.

Quality of Supply - Harmonics and Flicker

There are a number of ways of assessing the quality of supply. The usual measure is if the voltage goes outside the permitted tolerance. The voltage will vary with load, largely due to reactive power flow in the cables, and this can result in voltages being outside the permitted tolerance. This can result in motors overloading or stalling on start-up. Since the load variations are relatively slow they can be controlled by tap-changing transformers or reactive compensators.

Loads that pulsate can result in what is termed 'flicker'. This is a measure of the annoyance caused by the variation in voltage. This is due to the fact that voltage swings that are well within the voltage tolerance, but of a repetitive nature, can create annoyance to the consumer. This is usually in the form of visual annoyance caused by cyclic variation in the lighting level, but it can also result in variations in product quality due to machines responding to the variations in voltage. In the case of the generation from stream turbines the generators must be reversed four times per day. Although it is possible to run the generators up to speed so that no starting current is required, there will still be a significant inrush of current at the moment of connection. With low resistance rotors as is typical in induction generators, this can have a time constant of seconds and is likely to cause a noticeable flicker on the local system. This will happen with every generator and although each generator will be connected at a different instant, at certain periods of the day there will be a large number of these voltage dips.

It is clear that with an increasing number of elements connected to the system, more faults will occur and quality of supply will be affected. Careful design of protection is essential to minimise this problem.

If semiconductor equipment is used to provide a measure of speed control for the turbines then harmonics could present a serious problem. These can result in additional losses in the cables and transformers. In addition there are specified levels for acceptable harmonic content in a generated waveform and these must be met if the supply authority is to accept the power. Harmonic filters can be of significant size and cost and the necessity of their use must be carefully studied in any final design.

Protection Schemes

The protection systems must perform 3 vital functions:-

- the Public Electricity Supply (PES) Network must be protected against faults which may occur on the farm
- the farm must be protected against faults which may occur on the PES Network
- the farm must have the necessary protection to guard against any Electrical or Mechanical failure within the farm.

In Northern Ireland, the Engineering Recommendation G59/1/NI is the requirement which private generators must meet before they can obtain permission to generate in parallel with the Northern Ireland Electricity system. Indeed, many of the recommendations set down in G59/1/NI are embodied in the Electricity Supply Regulations (Northern Ireland) 1991 and as such are statutory requirements. In the system controlled by the Electricity Supply Board (ESB) in RoI the supply legislation regarding the quality and security of supply would require such a scheme to meet the current standards for the installation of new embedded generating plant.

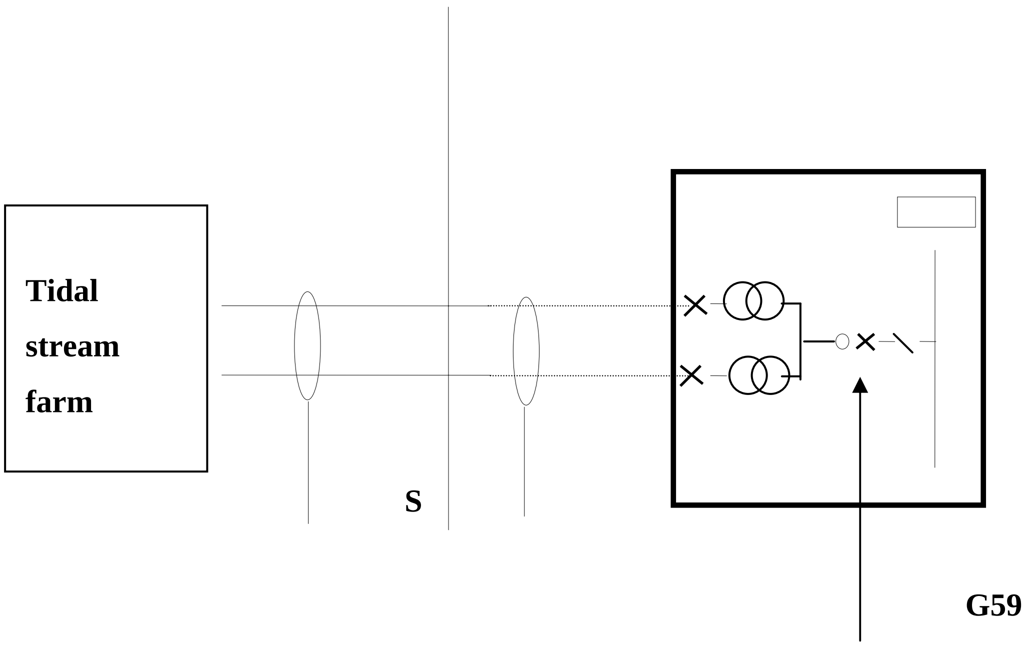


Fig.A6 Stream Farm to PES Network - basic arrangement

Fig.A6 shows the basic arrangement for connecting an offshore farm to the PES Network. The generator units are each connected to a high voltage ring main system which is then connected to a landline via submarine cables. The landline makes the final connection to the PES Network at a point deemed to be the Point Of Common Coupling (POCC). This landline can be either an overhead line or if the distance from the shoreline would make it economically feasible the final stage could be underground cables.

The use of transformers will depend on the cable to shore voltage and these may be unnecessary.

Protecting the Supply Network

For protecting the PES Network the G59/1/NI Regulations require the protection equipment to achieve the following objectives:-

- To inhibit connection of the generating plant to NIE's supply unless all phases of NIE's supply are energised and operating within the agreed protection settings.
- To disconnect the generator plant from the system when a system abnormality occurs that results in an unacceptable deviation of the voltage and frequency at the point of supply.
- To disconnect the generating plant from the NIE system in the event of loss of one or more phases of NIE's supply to the installation.
- To ensure either the automatic disconnect of the generating plant, or where there is competent supervision of an installation, the operation of an alarm with audible and visual indication, in the event of a failure of any supplies to the protective equipment, which would inhibit its correct operation.

To meet the above objectives the following basic forms of protection must be provided:-

a) Over Voltage
b) Under Voltage
c) Over Frequency
d) Under Frequency
e) Loss of Mains.

In addition to the above basic requirements it may be necessary to detect the following:-

a) Neutral Voltage Displacement
b) Overcurrent
c) Earth Fault
d) Reverse Power - above a preset limit.

Protection manufacturers today can provide a package that will comply with the regulations by covering all of the above requirements. It is then a matter of agreeing the settings to be applied with the appropriate Supply Authority.

ESB have a similar set of regulations. These are covered in detail in the 'ESB Transmission System Connection Standards' available from ESB National Grid. The relevant section would be CC12. Another relevant document that is also available from ESB is:- ' Process for Connection of a Power Station to ESB's Transmission System'.

Protecting the Farm from System Faults.

The protection described above will also provide the main protection required for the wind farm in the event of a fault on the PES Network.

In the event of a fault on the PES Network causing the Stream Farm system circuit breakers to open then the Wind Farm would be required to shut down or go into an idling mode. This would be achieved by sending a signal from the POCC tripping device back to the Wind Farm.

Wind Farm Protection

When considering the Wind Farm protection then two objectives must be met:-

- Protection of the individual generators and associated equipment from excessive damage in the event of a breakdown either within a single unit or on the farm network.
- Overall Farm protection designed to isolate a defective generator or feeder with the view to maintaining generation output from the farm in such an event.

Individual Generator Protection

The standard protection provided for any generating unit comprises the following:-

a) Generator Unit Protection
b) Generator Field Fail - if synchronous generators are used.
c) Generator Negative Phase Sequence
d) Generator Reverse Power
e) Generator Stator Earth Fault
f) Generator Overcurrent and Earth Fault
g) Generator Transformer Buchholz Trip/Alarm - if oil filled transformers used.
h) Generator Transformer High Temperature Trip.
i) Mechanical Protection devices
   - Generator Overspeed
   - Generator Excessive Vibration
   - Loss of Lubricating Oil or over temperature
   - Mechanical brake

Most, if not all, of the above would normally be supplied by the generator manufacturer.

Ovall Stream Farm Protection

The system of protection will depend upon the configuration of the farm circuit. Figs.A1 and A2 show two different system arrangements and the connections of the individual units are shown in Figs. A3, A4 and A5. The a goal of the protection is to ensure that if a fault occurs, then only the faulty component will be removed from the circuit. Thus if a fault occurs on a section of the cable, the faulty section can be isolated, the open breaker on the feeder closed and the system will continue to operate. This will happen automatically due to the protection relays.
Some of the protection issues will depend on the switchgear at the POCC and therefore it is usual to include a signal line in the farm to shore cable. This is typically a glass fibre link and could also be used for manual control of the units where necessary

In certain circuit breaker designs a circuit breaker can be withdrawn and locked such that it can provide the necessary isolation without the need for a circuit disconnector on the incoming side of the circuit breaker. That arrangement would be required for the system outlined here.

Power Control and Scheduling

Generation plant, which is operating on the system, will be subject to central control in that they will only generate power when asked to do so. In the case of non fossil fuels used for generation under the NFFO or AER tariffs there is an exception made in that the supply authority is obliged to accept all the electricity, which is generated in this manner. The increased cost is spread over the cost of the electrical units for the customers. If the situation arose where there was a significant amount of stream energy on the system then it could be used as a rapid means of power control since it could be brought on and off load very rapidly.

Communication Links

It is possible to operate a stream farm remotely by optical links. Thus, it is possible to control plant remotely and to download any data that will be needed. Such day-to-day control could best be exercised by a contractor who has the required expertise in maintenance and repairs.

If generation control were required, then there would need to be a link with the supply authority. For rapid control this would need to be a direct link so as to be able to respond rapidly to fault conditions. The supply authority would then be given the responsibility for power control within specified limits.

Other possibilities for control requirements would be if transmission lines were de-energised for maintenance requirements. Shut down of the wind farm or reduced output might then be necessary for a period. In such a situation the arrangements would need to be negotiated beforehand.