Development of an Optimal Reactive Power Compensation Scheme for Windfarm

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Abstract: A wide variety of reactive power consumption (RPC) solutions ranging from fixed capacitors to advanced static var compensators are available today. The paper illustrates design and development of an optimal compensation scheme custom made for windfarms combining the low cost & losses of a fixed capacitor with performance and flexibility of advanced static var compensators. The paper describes in detail the sizing of compensation, its configuration and features highlighting the special protection provided against self-excitation and resonance.

I INTRODUCTION:

The design of reactive power compensation (RPC) scheme for a windfarm posses new challenges due to its operating conditions and variation in reactive power requirements. The conventional power factor correction methods, applicable for normal industrial load fail in a windfarm due to various reasons presented in the next section. Due to its unique requirement, design of a reactive power compensation system for a windfarm calls for a thorough understanding of the system and a detailed analysis and demands special protection and functional features, which are generally not called for in conventional industrial power factor correction.

II CHARACTERISTICS OF RPC FOR WINDFARMS

The distinguishing characteristics of RPC for windfarms are

- The compensation requirement is not constant (fixed), but is time varying, over the entire operating period. The Var requirement varies widely with time and a minute to minute correction is required. The typical VAR requirement over a month is illustrated in fig. 1. Within a day the variations are much wider
- Low utilization factor due to seasonal variations. As evident from fig. 2, the VAR requirement is very high during high wind seasons and is very low during low wind seasons. This results in under utilization of compensation during low winds.
- The load (induction generator) is actually a source. This introduces problems associated with over compensation or self-excitation, especially when the generators are disconnected from the grid.
- Most of the Wind electric Generators (WEG) are connected to remote ends of lines and are subjected to harmonics and transients, which also affect the compensation
- The RPC is located at remote areas and manned by low level operators.

III CHALLENGES & REQUIREMENTS

Apart from the regular functional requirements the unique characteristics of WEG requires additional features and posses new challenges.

A. Challenges:

The challenges are

- Selection of an appropriate technology to provide an optimal solution. The technology must be suited for frequent switching at the same time not very expensive as the total compensation is highly under utilized.
- Special protection against self-excitation and resonance due to harmonics present in the system

B. Requirements:

The characteristics of VAR compensation for WEG and the challenges translate into the following requirements of the compensation system.

- The compensation must be tailor made for the specific application and should aim at improving the overall operational efficiency of the windfarms (and also the T & D network)
- The solution must be optimal and should have a low life cycle cost (capital + operating cost) and should be based on a techno-economic solution.
- The compensation must be a controllable current source that can give the required power factor.
- The compensation system must be completely self protected and must have protection features to protect the WEG from self-excitation.

While designing the cost of reactive power, present (and future) penalty for reactive power consumption, cost of real power, system detail and WEG characteristics are used as major design inputs.

IV SIZING:

The first step in design in the proper sizing of the compensation system. It is evident from the operating data that the maximum size of the compensation required would be very high based on daily data to avoid any penalty. But such a large size of compensation would be very expensive and might not meet the commercial payback terms. Also the cost would be dependent on the configuration. An iterative approach is used to arrive at the optimal size where the reduced capital investment (due to lower size) outweighs the penalty to be paid. The size is so chosen as to maximize the customer benefit to cost ratio function.

V CONFIGURATION SELECTION:

The next step is to optimally configure the selected size. This essentially is to select the type of compensation and its location.

A. Selection of type of compensation scheme:

The various types of compensations considered are as follows.

i. Fixed capacitors (FC): Though these are the least expensive and the most efficient (very low losses) they have the disadvantage of not meeting the VAR requirement under all operating conditions. To avoid VAR import the size must be the largest required, which implies large VAR exports during low wind seasons. This could affect the voltage stability margins adversely. Also there exists a strong possibility of over compensation and self-excitation (especially when an upstream breaker opens) leading to over-voltages and over speeds which could be catastrophic.

ii. With mechanically switched capacitors (MSC) (be it directly connected on the HV side or connected on the LT side through a step down transformer) the problems associated with fixed capacitors can be eliminated. But MSC's have the problem of switching inrush currents and capacitor over-voltages due to multiple restrikes. The switching duty is very severe in a windfarm application as evident from the hourly variation of VAR requirement. Also connection of MSC on the LT side through a transformer introduces additional losses in the system. Series reactor with MSC to limit the switching current introduces an additional lossy component in the system.

iii. Thyristor switched capacitors (TSC) are better suited for frequent switching operations but are more expensive and lossier compared to FC's. Also for the power ratings being considered direct HT connection is not viable and TSC needs to be connected to the Point of Common Coupling through a step up transformer, another source of power loss. TSC has a very high operational flexibility and switching performance.

iv. SVC (FC + TSC + TCR) / ASVC: Though these are high on performance with regard to flexibility and switching, these devices are very expensive and have a high loss associated with them. Also these devices generate harmonics during their operation.

Based on the above and the design input a configuration is chosen as to combine the best features of all types of compensations listed above. A hybrid configuration is chosen, which is made up of appropriate sizes of FC, MSC & TSC. The FC is directly connected to the line and has a very low cost and loss. This is used to meet the base Q requirement that exists throughout the year. The MSC instead of being connected through a transformer is directly connected to the HT side and is switched through a HT circuit breaker with current limiting devices. This avoids the cost and losses associated with a step down transformer. The size of this is so chosen that it will be automatically switched in during the start of high wind and will be switched out before the start of low wind season. This reduces the number of switching operations thus increasing the reliability of the system. The TSC portion is sized so that it meets only the fast variations in VAR requirement (variations on a minute to minute basis). The TSC is connected through a step up transformer. The entire configuration is so chosen to reduce the overall cost (life cycle cost) and maximize the operating efficiency. This hybrid configuration has an overall annual efficiency of > 99.5% and has the flexibility and ability for fast & frequent switching associated with SVC / ASVC.

B. Selection of location:

As regard to the location of the compensation it can be located at one of the following.

- At individual machine terminals (individual compensation), catering to only one machine.
- At the service connection (point of common coupling) catering to a large number of WEG's

connect at that point (where usually the utility metering is done)

- At the sub-station, catering to the entire windfarm, comprising of a large number of individual service connections.

A Detailed techno-economic analysis considering practical aspects of implementation was conducted and the best location was found to be that of connection to service connection, catering to a group of WEG's. This type of group compensation has a lower overall cost and operational ease.

VI THE NEW CONTROLLER

The next step is to develop an appropriate controller & control logic which would meet all the challenges and requirements. VARTROL ®, a special controller developed by Crompton Greaves Ltd. is specially developed for windfarm reactive power compensation applications and has the following features, which are not normally present in most other conventional controllers.

A. Protection features.

Apart from routine protections against under voltage, over voltage, over current, short circuit, earth fault and over temperature, special protection is provided against resonance and self- excitation.

B. Control layers.

Three control layers are provided for enabling constant current operation, constant voltage operation and Q control operation. This is illustrated in fig.3

C. Control modes

There are four modes of operation of the controller to give an optimum performance. The modes of operation are detailed in section IX.

VII SPECIAL PROTECTION FEATURES:

A. Protection against self-excitation:

This is a special feature built into the system specifically to cater to windfarms. Since most wind electric generators employ induction generators as electromechanical energy converters, the capacitance connected across the IG must be immediately disconnected as soon as the grid drops. This is achieved through special hardware and software. Immediately (< 20ms) on disconnection from the grid, the TSC portion is switched off, thus reducing the capacitance to a value lower than the critical value. The breaker switched capacitor is than switched off in less than 100ms to prevent any over voltage or over speeding of the induction generator.

B. Protection against resonance:

The controller is designed with a special feature to automatically detune the entire compensation system if a resonance condition is detected. If a resonance occurs, it is immediately detected using a special logic and instead of switching out the entire compensation, the controller is programmed to detune the compensation system by a special switching logic which changes the net impedance of the compensation. By this a part of the compensation is still available for power factor improvement.

VIII SPECIAL CONTROL LAYERS:

A. Q Control Layer

The controller operates in this layer for most of the time. In this control layer, the controller tries to switch in the appropriate capacitor banks (branches) required to meet the VAR requirement.

B. Current Control layer

When the system voltage increases (and if the VAR requirement is also at its maximum) the current through the TSC and the step up transformer increases. This can overload the transformer. Under these conditions instead of tripping out the entire system, control logic is built into the system as to switch out some TSC branches as to reduce the line current. This increases the availability of the compensation to a greater extent. With this control a constant (maximum) current can be maintained through the TSC, irrespective of the system conditions

C. Voltage Control Layer.

If the system voltage increases the voltage on the TSC also increases proportionally. Apart from this the voltage on the capacitors are higher than the system voltage (HT voltage / transformation ratio) due to drop across the leakage impedance of the interconnected transformer, being added to the system voltage. This results in an over-voltage across the capacitors. Under such conditions the current through the transformer is controlled to control the voltage boost through switching out some of TSC branches. This is done in order not the trip the entire system on over-voltage, but to have atleast some Q available thereby increasing the availability

IX SPECIAL MODES OF OPERATION:

There are four modes of operation of the controller to give an optimum performance. The modes of operation are

A. Manual mode

In this mode the operator can select and manually switch on the required capacitor banks (branches)

B. Auto mode – Unity power factor mode

In this mode the controller automatically switches on the appropriate capacitors to maintain a unity power factor at the PCC.

C. Auto mode – Target power factor mode

In this mode the controller automatically switches on the appropriate capacitors to maintain the set (target) power factor at the PCC.

D. Auto mode – Optimum power factor mode.

This is a very unique mode of operation, where the controller switches in those capacitors as to reduce the net line current irrespective of the power factor. This is very useful when the line voltage has harmonics and maintaining unity power factor (as measured at fundamental frequency) does not necessarily reduce the line currents and hence the T & D losses. This mode ensures that the losses are minimal, irrespective of the power factor, which is the primary purpose of reactive power compensation.

X. OTHER FEATURES

Other features of the developed compensation system include:

1. Automatic checks to detect if any thyristor has failed.
2. RS- 232 communication interface for data logging and remote control
3. User friendly mimic and front panel

4. Auto restart facility for under voltage, over voltage & over temperature faults and lock out facility for repeated over current fault.

XII RFERENCES

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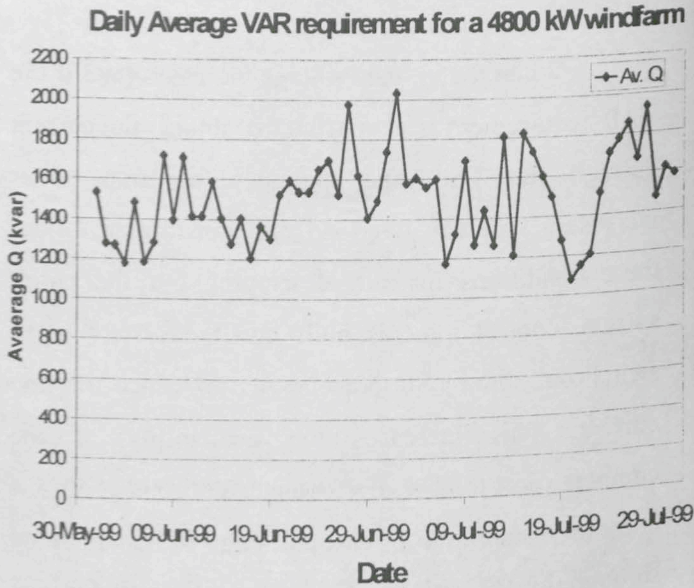

Fig. 1 Daily average VAR Requirement

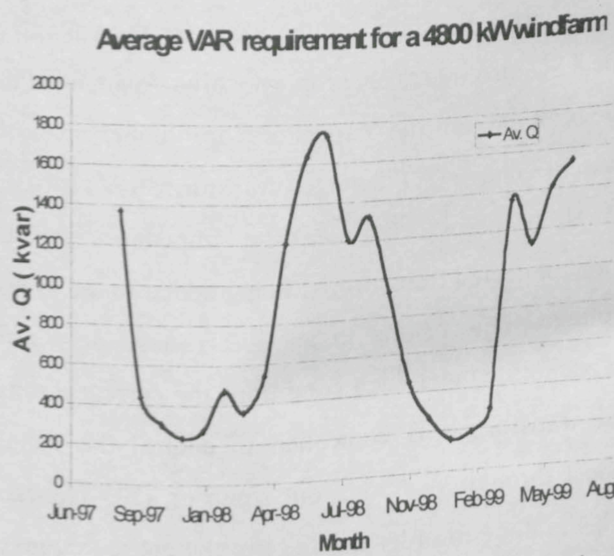

Fig. 2 Annual average VAR Requirement

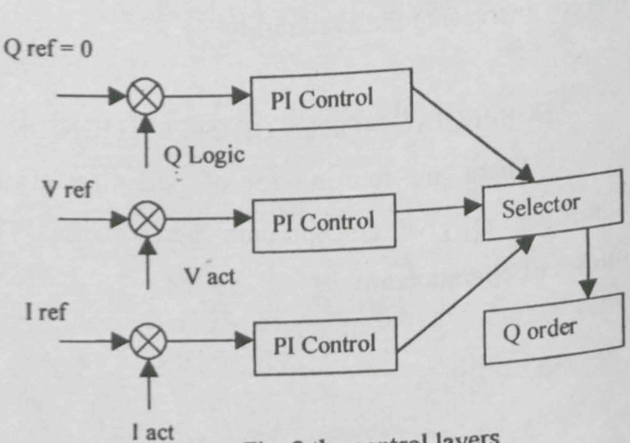

Fig. 3 the control layers