IMPACT OF SVC AND DSTATCOM DEVICES ON INDUCTION GENERATOR PROTECTION SYSTEM

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Abstract – **This work presents an investigation about the impact of SVC (Static Var Compensator) and DSTATCOM (Distribution Static Synchronous Compensator) devices on the protection system of induction generators. Computational simulation results show that these devices may adversely influence the performance of under/over voltage relays employed to protect induction generators during islanding.**

Keywords - **DSTATCOM, induction generator, protection system, SVC, under/over voltage relays.**

I. INTRODUCTION

Recently, the usage of distributed generation has increased driven by market deregulation, technological developments, governmental incentives and environment concerns. In this context, induction generators have received more attention, which have been employed in thermal, hydro and wind generation plants [1]-[4]. Such kind of generator requires an external excitation source in order to produce electrical energy. Although an induction generator can draw its magnetizing current from the distribution system, usually reactive power compensation devices are installed near the unity. The most common option is the installation of fixed-shunt-connected capacitors at the generator terminals. Another possibility is to install dynamic reactive power compensation devices. In this case, the SVC (Static Var Compensator) and the DSTATCOM (Distribution Static Synchronous Compensator) are two devices that can be used to provide the excitation and improve the stability performance of induction generators [1], [5].

In addition, one of main elements employed in the protection system of induction generators is the under/over voltage relay. Such relays are used to disconnect the induction generators during islanding and faults. However, in the presence of dynamic reactive power compensation devices, the voltage may be kept constant during an interval of time long enough to affect the performance of voltage-based protection systems.

Based on these facts, it is important to determine the impact of dynamic reactive power compensation devices on performance of under/over voltage relays. Therefore, this work presents a preliminary investigation about the impact of SVC (Static Var Compensator) and DSTATCOM (Distribution Static Synchronous Compensator) devices on the protection system of induction generator based on under/over voltage relays. This study is carried out through dynamic simulations considering different scenarios and compensation levels.

II. VOLTAGE RELAY-BASED PROTECTION SYSTEM OF INDUCTION GENERATORS

One of the main elements employed in protection systems of induction generators is the under/over voltage relay. Such relays are used to disconnect the induction generators mainly during islanding and faults. Islanding occurs when a portion of the distribution system becomes electrically isolated from the remainder of the power system, yet continues to be energized by distributed generators. Failure to trip the distributed generators during islanding can lead to a number of problems to the generators and connected loads. Therefore, the current industry practice is to disconnect all distributed generators immediately after an islanding occurrence [6]-[9]. Typically, a distributed generator should be disconnected between 200 and 400 ms after loss of the main supply. In the case of induction generators, under/over voltage relays have been used to islanding detection purposes. In addition, it is well recognized that induction generators are practically unable to supply sustained short-circuit currents during faults. This is an important fact because, in this case, the generator protection system may not be able to detect the fault in the network. However, during faults, the terminal voltage of induction generators decreases considerably. Thus, under/over voltage relays can be used to detect faults.

III. DYNAMIC REACTIVE POWER COMPENSATION

Reactive power compensation has been used in distribution systems for many years by using mechanically switched capacitors/reactors. In this case, the control is carried out in a discrete (step) way [5]. More recently, with the advanced of power electronic components, continuous control devices have been developed [5]. In distribution level, the most common devices are the SVC and the DSTATCOM, which are briefly discussed in the next sections.

A. Static Var Compensator (SVC)

A typical configuration of a SVC is shown in Fig. 1. Such device is developed by combining thyristor-controlled reactors (TCRs) and thyristor-switched capacitors (TSCs), which are connected to the network through a coupling transformer. As a consequence, from the operational point of view, a SVC behaves like a shunt-connected variable reactance [5]. In this case, generally, only thyristors without gate turn-off capability are employed. This device has been extensively used for reactive power and voltage regulation since 70's years.

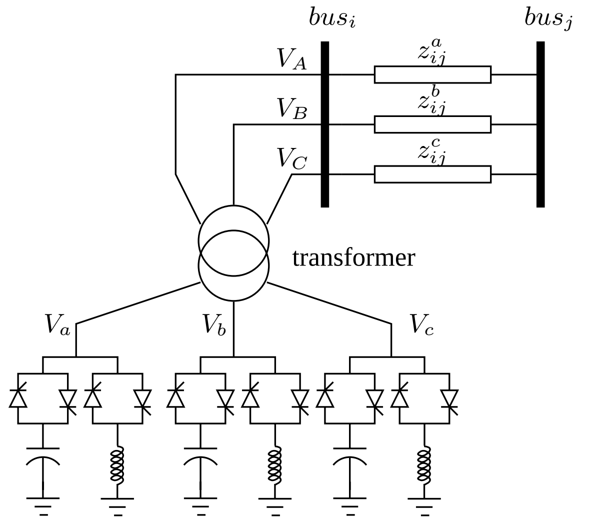


Fig. 1 SVC structure.

The SVC voltage controller adopted in this work is presented in Fig. 2. In this figure, V_{rms} is the rms terminal voltage, I_{svc} is the reactive current injected (or consumed) by the SVC into (from) the network, V_{rms}^* is the voltage reference and X_s is the droop reactance, usually 5%. The signal error is processed by a PI regulator. The output signal is the desirable SVC equivalent reactance. Based on the value of X_{SVC}, the control circuit determines the number of capacitors that must be switched and/or the angle α of TCRs. The switching instants are synchronized with the three-phase voltages V_{abc}.

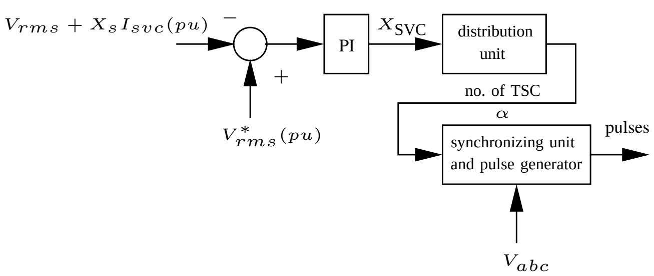


Fig. 2 SVC voltage controller.

B. Distribution Static Synchronous Compensator (DSTATCOM)

A DSTATCOM, which is schematically depicted in Fig. 3, consists of a three-phase voltage source converter shunt connected to the distribution network through a coupling transformer [5]. This configuration allows the device to absorb or generate controllable reactive power. The DSTATCOM has been utilized for voltage regulation, correction of power factor and elimination of current harmonics [5]. In distribution voltage level, the switching element is usually the IGBT (Integrated Gate Bipolar Transistor), due to its lower switching losses and reduced size. Moreover, the power rating of these devices is relatively low. Consequently, the output voltage control may be executed through PWM (Pulse Width Modulation) switching method.

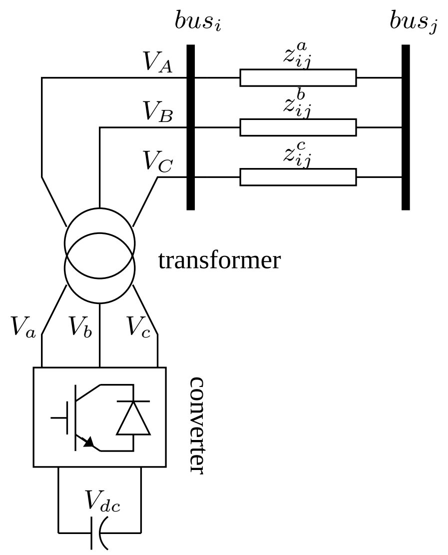
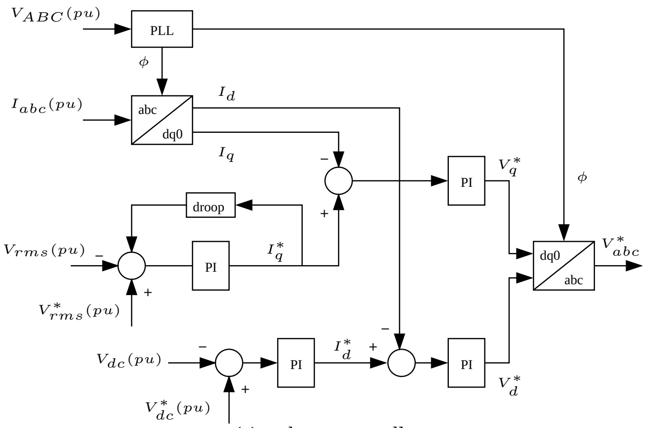


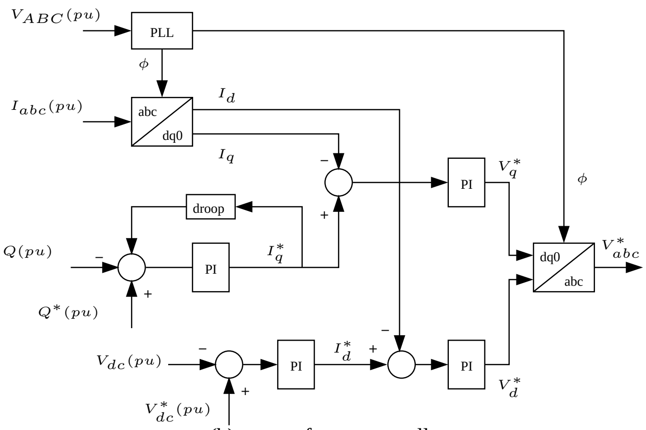
Fig. 3 DSTATCOM structure.

In this work, the DSTATCOM is controlled to regulate the terminal voltage or power factor. The voltage controller analyzed here is exhibited in Fig. 4(a), which employs the *dq0* rotating reference frame because it offers higher accuracy than stationary frame based techniques [5]. In this figure, V_{ABC} are the three-phase terminal voltages, I_{abc} are the three-phase currents injected by the DSTATCOM into the network, V_{rms} is the rms value of the terminal voltage, V_{dc} is the dc voltage measured in the capacitor and the superscripts * indicate reference values. Such controller employs a PLL (Phase Locked Loop) to synchronize the three-phase voltages at the converter output with the zero crossings of the fundamental component of the phase-A terminal voltage. Therefore, the PLL provides the angle ϕ to the *abc-to-dq0* (and *dq0-to-abc*) transformation. There are also four PI regulators. The first one is responsible for controlling the terminal voltage through the reactive power exchange with the ac network. This PI regulator provides the reactive current reference I_q^*, which is limited between +1 pu capacitive and −1 pu inductive. This regulator has one droop characteristic, usually ±5%, which allows the terminal voltage to suffer only small variations. Another PI regulator is responsible for keeping constant the dc voltage through a small active power exchange with the ac network, compensating the active power losses in the transformer and inverter. This PI regulator provides the active current reference I_d^*. The other two PI regulators determine voltage reference V_d^* and V_q^*, which are sent to the PWM signal generator of the converter, after a *dq0-to-abc* transformation. Finally, V_{abc}^* are the three-phase voltages desired at the converter output.

The power factor controller investigated here is shown in Fig. 4(b). This controller is very similar to the voltage controller previously presented. The main difference is the reactive power exchange controller, which is generally tuned to provide all reactive power demand at the consumer facility, i.e. unitary power factor operation. Thus, the reactive power reference Q* is generally set equal to zero and Q is the reactive power measured at the customer supply point. The other elements of this controller have already been previously explained. A practical example of a DSTATCOM power factor controller is a 8 MVAr DSTATCOM that was installed on a 24 MW wind farm in Denmark, whose control system is arranged so that the wind farm generates at unity power factor [1].



(a) voltage controller



(b) power factor controller

Fig. 4 DSTATCOM controllers.

IV. IMPACTS ON VOLTAGE RELAYS

Electromagnetic transient simulations are used for this investigation. All network components are represented by three-phase models. Distribution feeders are modeled as series *RL* impedances. Transformers are modeled using *T* circuit. The induction generators are represented by a eighth-order three-phase model in the *dq* rotor reference frame [8] and the mechanical power is considered constant. Fig. 5 shows the single-line of the test network, which consists of a 132 kV, 60 Hz, subtransmission system with short-circuit level of 1500 MVA, represented by a Thévenin equivalent (Sub), which feeds a 33 kV distribution system through a 132/33 kV, Δ/Yg, transformer. In this system, there is one induction generator with capacity of 30 MW connected at bus 5, which is connected to network through one 33/0.69 kV, Δ/Yg, transformer. The islanding situation is simulated by opening the circuit breaker CB at bus 2 at t = 0.250 second. It is also considered that there is automatic reclosing, which is simulated by closing the circuit breaker CB at bus 2 at t = 0.550 second. A three-phase-to-ground short-circuit is applied to bus 3 at t = 0.250 second, which is eliminated in t = 0.550 second without branch tripping. The dynamic behavior of terminal voltage for these cases is shown in Fig. 6(a) and (b), respectively. It can be verified that, during islanding, the presence of the DSTATCOM or the SVC controlled by voltage decreases considerably the voltage sags. Such fact can become difficult to detect an islanding situation. On the other hand, if the DSTATCOM is controlled by power factor, the voltage sags is more abrupt. In addition, during the three-phase short-circuit, the presence of the DSTATCOM or the SVC has not influence on the voltage sag..

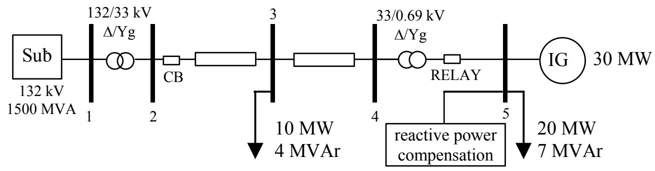
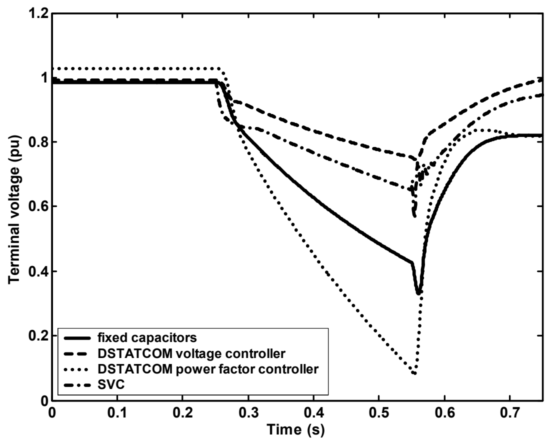
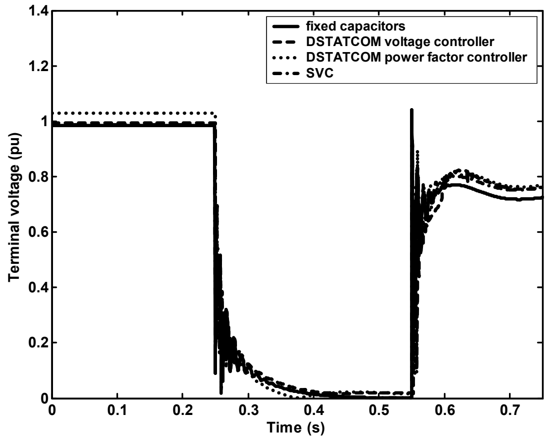


Fig. 5. Single-line diagram of the test system.



(a) islanding



(b) short-circuit.

Fig. 6 Terminal voltage during electrical perturbations.

V. ISLANDING DETECTION INVESTIGATION

The test system presented in Fig. 5 is adopted to investigate more detailing the islanding detection question. As discussed previously, in all analyzed cases, the islanding situation is simulated by opening the circuit breaker CB at bus 2 opens at t = 0.25 second, which remains open during the rest of the simulation. The total simulation time is 0.75 second. Therefore, if the under/over voltage relay installed at bus 5 does not detect the islanding condition until 0.5 second after opening of the circuit breaker CB, it is considered that the device is inoperative for this case. At the islanding instant, the induction generator is injecting 30 MW into the network. Different relay settings and compensation levels are analyzed.

The simulation results are summarized in Table I. In this table, *ND* means Not Detected. It can be observed that in the presence of dynamic reactive power compensation devices controlled by voltage the successful islanding detection is much more difficult. It is quite reasonable because, in this case, the nodal voltages take longer to decrease due to reactive power support. The larger the compensation capability is, the larger the detection time is. On the other hand, if the DSTATCOM is controlled as power factor regulator, the islanding situation is detected fast.

TABLE I
ISLANDING DETECTION TIME

		Capacitor cases		
		Detection time (second)		
Relay setting (pu)		Compensation level		
under	over	5 MVAr	10 MVAr	15 MVAr
0.8	1.2	0.1191	0.1441	0.1911
0.7	1.3	0.1584	0.1956	0.2629
0.6	1.4	0.2054	0.2553	0.3465
0.5	1.5	0.2611	0.3261	0.4456
		SVC cases		
		Detection time (second)		
Relay setting (pu)		Compensation level		
under	over	5 MVAr	10 MVAr	15 MVAr
0.8	1.2	0.1645	0.2119	0.4998
0.7	1.3	0.2365	0.3347	ND
0.6	1.4	0.3199	0.4759	ND
0.5	1.5	0.4183	ND	ND
		DSTATCOM voltage controller cases		
		Detection time (second)		
Relay setting (pu)		Compensation level		
under	over	5 MVAr	10 MVAr	15 MVAr
0.8	1.2	0.1910	0.3054	ND
0.7	1.3	0.2767	ND	ND
0.6	1.4	0.3888	ND	ND
0.5	1.5	ND	ND	ND
		DSTATCOM power factor controller cases		
		Detection time (second)		
Relay setting (pu)		Compensation level		
under	over	5 MVAr	10 MVAr	15 MVAr
0.8	1.2	0.1440	0.1427	0.1428
0.7	1.3	0.1805	0.1691	0.1599
0.6	1.4	0.2213	0.2000	0.1840
0.5	1.5	0.2671	0.2336	0.2105

VI. CONCLUSIONS

This work presented an investigation about the impact of DSTATCOM and SVC devices on the under/over voltage relays employed to protect induction generators. Computational simulation results showed that the usage of dynamic reactive power compensation devices controlled by voltage could become difficult the islanding detection by using common under/over voltage relays. On the other hand, if the DSTATCOM is controlled as power factor regulator, the islanding situation is detected fast. In addition, such devices has no influence on voltage relay performance during three-phase short-circuits.

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