Remote Control System for Transformers with On-Load Tap Changer

K.J. Sagastabeitia[1], Z. Aginako[1], A.J. Mazón[2] and I. Zamora[2]

[1] Department of Electrical Engineering
E.U.I.T.I. of Bilbao, University of the Basque Country
Plaza de La Casilla nº 3, 48012 Bilbao (Spain)
phone:+34 94 601 4371, fax:+34 94 601 4300, e-mail: iepsabuk@lg.ehu.es, iepagars@lg.ehu.es

[2] Department of Electrical Engineering
E.T.S.I. of Bilbao, University of the Basque Country
Alda. Urkijo s/n, 48013 Bilbao (Spain)
phone:+34 94 601 4063, fax:+34 94 601 4200, e-mail: iepmasaj@bi.ehu.es, iepzabei@bilg.ehu.es

Abstract. This paper presents a Remote Control System for Transformers with On-Load Tap Changer. This tool has been designed to be implemented in Remote Telecontrol Units (RTU) located in Transformation Centers (CT) with on-load tap changing capability. Its final application is to provide an integral solution of the telecontrolled on-load tap changer from a Remote Operation Control Position (ROCP), located into the electric company´s operation office.

Key words: Power System Control, Voltage Control, Power Transformers, Tap Changer, Remote Control.

1. Introduction

One of the main concerns of electrical utilities is the power quality. Customers demand uninterrupted supply with minimum disruption. In this sense, voltage stability and security assesment implies network loading and voltage control evaluation.

Also, taking care of security and economic reasons, network operation demands suitable management of available resources. So, electrical utilities are forced to carry out an effective control of power flow (active and reactive) derived by the different circuits that compose the power system.

In this way, it is essential to control and regulate the system voltage in those network busbars that, due to their importance or location, allow to guarantee:

- Maintenance of voltage and frequency within the established limits.
- Power supply continuity.
- Control of power flows according to operation needs.

There are different existing devices to achieve this goal. But transformers, with on-load tap changing capability, are quite commonly applied to regulated bus voltage for a long time. [1]

So, over last years, several researchers have analyzed the dynamic operation of on-load tap changers (LTC). These investigations try to obtain a model that simulates their behavior with enough precision [2][3]. Also, they have tried to develop control algorithms, methods and techniques to make possible the use of transformers with LTC in an automated, efficient and safe way. [4]-[9]

2. System configuration

The Transformation Centers where this Remote Control System (RCS) can be implemented are totally automated and all operations are remotely controlled, except those corresponding to local automatisms. For this reason, they do not require the permanent presence of personnel and their actions are reduced to preventive and corrective maintenance operations.

The remotes are telecontrolled from the corresponding Remote Operation Control Position through a RS-232 series communication, whose physical connection (series interface + communication modem) is duplicated for security reasons. In this way, using a mechanism that supervises the connection and its automatic commutation, communication is guaranteed after a failure, in some of its components, happens. Also, it is possible to maintain the security standards that are required, nowadays, for this type of installations.

The proposed system has been developed with equipment of the Sisteam A range. Sisteam A is a multiprocessor modular system for application in industrial control. It can be used in different ways with very fast response times. The systems developed with Sisteam A can be conformed easily to changes in the configuration of the controlled facilities or modifications in size due to future extensions. It is sufficient to add the necessary modules and suitably readjust of certain parameters.

It has a modular structure (hardware and software). Also, it constitutes a totally independent entity that is able to be related, permanently and automatically, to the process.

The local part of the automatism has been developed by means of specific control functions that work in a semi independent way. The basic aim of the On-Load Tap Changer Control (LTCC) function is to take the commutator from the present tap to the wished final one. So, it is feasible to regulate the voltage level in the secondary of transformers by means of control of their tap´s position.

The automatism –as a whole– is able to control eight transformers, so it includes eight LTCC functions. Each function governs the commutator of one position.

The activation of LTCC functions is remotely controlled from the ROCP. And, before sending this command, remote operator has to establish the position set point (number of tap which the system must take the commutator to).

Both information (activation and position set point) are generated by the ROCP and function LTCC gathers them from the corresponding communication channel.

Deactivation of one LTCC function can take place by different causes:

- Deactivation from the ROCP.
- Auto – deactivation of the function when operation concludes. In general, this is because the wished position has been reached.
- Auto – deactivation of the function by operation failure or incorrect programming.

In the first case, deactivation command leaves from the ROCP by decision of the system operator. In the last two cases, the own LTCC function generates deactivation command, when detects that operation has been culminated successfully, or that some problem hinders it from reaching the wished tap.

With this aim, LTCC function has been equipped with the necessary subroutines to make an exhaustive watching of the process and to verify its good development. In this way, correct operation of the system is supervised considering auto – test mechanisms of SISTEAM A / SISTEAM TMX equipment [10][11], such as supervision of:

- Central Processing Unit (CPU).
- Digital and Analogic Input cards (DI and AI).
- Digital and Analogic Output cards (DO and AO).
- Communication card.

LTCC function verifies the fulfillment of all the commands generated. In adition, detection of possible failures in the equipment hardware or in signal processing is made externally to this automatism. Thereby, after a determined control command is done, corresponding change in associated entrance to this order is expected.

So, after a certain time from a command output (for example: raise up transformer tap), if awaited change (tap goes to a superior position) is not detected, it is understood that something has failed. Then, function is deactivated and it generates the corresponding warning message.

The time delay to generate this message (failure by unsuccessful command) is settled on by means of a parameter. The value of this parameter can be modified and fitted "in situ", taking care of the own characteristics of each case (speed in the tap changing of each commutator, cycle time of each remote…).

As it already has been said, each LTCC function controls the commutator of one transformer. But in some cases, transformers can work in parallel. Moreover, those transformers that works connected in parallel can be equal or different. Treatment is different according to these circumstances. Thus, in the first case both transformers must have always the same tap position. So, when activated, the automatism verifies that the position set points of equal transformers that work in parallel are the same. Otherwise, LTCC functions of both transformers are deactivated and it is generated the corresponding warning signal, without carrying out additional operation.

If transformers that work connected in parallel are different, their tap position set points can be different. In this case, the relation between both transformers must be well–known. The automatism will watch that difference between their taps no surpasses, at any moment, a threshold value that is fixed by operator from the ROCP. This value is settled on by means of a parameter wich can be modified.

3. Forms of LTCC function

LTCC function works according to some forms that respond to different types of transformers that can be installed in these Transformation Centers.

A. HV/MV Transformers

In this case, the object of LTCC function is to reduce the voltage level, to decrease the load in the network when emergency situations happen.

Within HV/MV transformers, autonomous transformers and non autonomous ones can be distinguished.

1) *Autonomous transformers.* In this case, there is an external regulator that directly receives the position set point from the ROCP. This regulator takes the commutator to the wished tap position.

Therefore, the remote does not need any LTCC function for this type of transformers.

2) *Non autonomous transformers.* In this case, there is an external regulator to take the transformer to prefixed tap position. The aim of LTCC function is to decrease the voltage until a reduced level. This level is fixed by the tap position set point that arrives from the ROCP when the automatism is activated.

B. HV/HV Transformers

As some HV/HV transformers have the possibility of working connected in parallel, the operation of these units is specifyed from the ROCP by means of a modifiable parameter. So, two transformers connected to the same busbar can work individually or in parallel according to the operation requirements.

In the case of independent transformers (not prepared to work in parallel), the previous parameter will be always in on the "individual" setting and it will not be modifiable.

On the other hand, the process of function activation begins with the transmission from the ROCP of the tap position set point, followed by the activation command of the corresponding LTCC function.

The function deactivation, in addition to the reasons commented in the case of HV/MV transformers, takes place if the regulator passes to automatic control when LTCC function is in process.

Within this type of transformers, it can distinguish between:

1) *Independent transformers.* "Individual/Parallel" parameter, that fixes the operation of the transformer, is not modifiable and will be always on "Individual" position.
The automatism supervises the fulfillment of all operation commands. In case of detecting some failure by unsuccessful command, the process is interrupted, LTCC function is deactivated and corresponding failure signal is generated.

2) *Transformers connectable in parallel.* In this case, "Individual/Parallel" parameter will be modifiable by the operator from the ROCP.
There is only one signal for both transformers susceptible to work in parallel. So, each pair of LTCC functions will work in parallel or individual way according to the value of this common parameter.

If the signal, corresponding to the operation of parallel connectable transformers, is on individual position, the process followed by each LTCC function will be the same as the case of independent transformers.

However, in the case of transformers that can work in parallel, three different situations can be established:

- Neither of both transformers has regulator. Each LTCC function acts on its transformer like in the independent units, directly sending the orders to the commutator until taking it to the wished tap.

- Both transformers have the same regulator. The regulator must be on manual control to activate their LTCC functions. If regulator pass to automatic control while automatism is running, both LTCC functions will be deactivated and the corresponding signals will be generated.

- Each transformer has a different regulator. The regulator of each transformer must be on manual control to activate their LTCC function. If regulator pass to automatic control while automatism is running, only affected LTCC function will be deactivated. Warning signals will be generated.

If transformers work in parallel and they are equals, the activation of their LTCC functions is only possible when both of them are simultaneously activated and it is made according to the following sequence:

- ROCP sends the same position set points for both transformers.

- ROCP sends the order to activate both LTCC functions.

Also, the three possibilities already reviewed in the previous case can be found here:

- Neither of both transformers has regulator. Before activating LTCC functions, it is verified that activate commands for both transformers have been received and their position set points are equal. If not, both functions will be deactivated and the corresponding signals will be generated.
Only the commutator of the first transformer is activated to get the wished tap.

- Both transformers have the same regulator. Before activating LTCC functions, it is verified that activate commands for both transformers have been received, the regulator is on manual control and their position set points are equal. If not, both functions will be deactivated and the corresponding signals will be generated.
Only the commutator of the first transformer is activated.

- Each transformer has a different regulator. The process is the same followed in the previous case. But in this case, only the commutator, established by means of a modifiable parameter by the operator from the ROCP, is activated.

The sequence and conditions to activate LTCC functions of different transformers working in parallel are the same ones that those defined for equal transformers working in parallel. However, with different transformers, position set points for both transformers not necessarily must be equal. So, for the three seen options, the following operation characteristics can be established:

- Neither of both transformers has regulator. Before activating LTCC functions, it is verified that activate commands for both transformers have been received.
  Each commutator whose position set point is different from the present position is activated until the wished taps are achieved.
  LTCC functions manage this operation. So that, the specified highest difference between taps is not surpassed at any moment.

- Both transformers have the same regulator. Before activating LTCC functions, it is verified that activate commands for both transformers have been received and the regulator is on manual control. If not, both functions will be deactivated and the corresponding signals will be generated.
  Each commutator whose position set point is different from the present position is activated and the specified highest difference between taps is not surpassed at any moment.

- Each transformer has a different regulator. The process is the same followed in the previous case. Both regulators must be in manual control.

In the three cases, it is responsibility of the automatism that the difference between the tap positions of both transformer does not surpass the highest difference fixed from the ROCP by means of a modifiable parameter. During this process, if it is no feasible to continue without surpassing it, LTCC functions will be deactivated and corresponding signals of warning will be generated.

4. Development of the automatism

The automatism presented in this paper consists of eight LTCC functions (LTCC1 to LTCC8) grouped by pairs in four logic functions.

Each one of these four logic functions processes and manages the information of two transformers that, in general, will be able to work in parallel. These data, received from the ROCP or gathered from input cards, are used to control the tap position of the LTC transformers. LTCC functions carry out the necessary orders to verify the correct execution of generated commands.

Also, it is generated a series of signals and data, wich provides complete information about the state of the automatism. The most significative data is sent to the ROCP or presented for “on line” monitoring. All these input and output signals are specified in next section.

When developing this automatism, it has been tried to simplify its operation and configuration, in order to obtain homogenization and standarización which make possible its use in the greatest possible number of remote units.

On the other hand, it has been used a modular programming. The operation process has been subdivided into defined and delimited states, that makes easier its monitoring or modification for technicians initiated in these types of systems. Also, the transitions between those states have been clearly located. Control of tap positions has been developed as an independent subroutine, since it is recurrently used in most of the programming states.

Finally, it can be highlighted that this automatism has been implemented in already existing remote units. Therefore, these remote units develop many other functions, mainly those regarding to telecontrol. Thus, the RCS for transformers with LTC has been integrated in RTUs as a semi-independent module, wich interchanges signals and information with the process by means of input/output cards and with the ROCP via series communication card.

5. Signals interchange

In this section, inputs, outputs and parameters used by LTCC functions, as well as the signals that they interchange with the ROCP are specified.

A. Digital inputs

These inputs have binary character and provide information about the state of the different elements of the Transformation Center. The main digital inputs are:

- Control position of the regulator of each transformer (Automatic/Manual).

B. Numeric inputs

Numerical information codified in 32 bits that has been externally processed. LTCC functions receive it as a whole number between 1 and 32.

- Tap position of each transformer.

C. Binary signals from the ROCP

They are signals with binary character that the LTCC functions gather from the corresponding communication channel.

- LTCC functions activation commands. Their value must be “1” until the function is deactivated by the ROCP or by own automatism.

- Type of transformer (HV/MV or HV/HV).
- Operation for each pair of transformers (Parallel/Individual).
- Characteristics of transformers which can work in parallel (Equals/Differents). This signal is for transformers working in parallel.
- Selected commutator (T1/T2). This signal is used for equal transformers working in parallel.
- Voltage level command (Pass to lower voltage / Return to normal voltage). This signal will only exist for HV/MV transformers.

D. Numerical signals from the ROCP

Numerical information gatehered by the LTCC funtions from the corresponding communication channel.

- Tap position set point for each transformer.
- The highest difference between taps of transformers that work in parallel. This signal is used for different transformers working in parallel.

E. Digital outputs

Digital outputs are binary orders, generated by the automatism. They are executed externally on elements of the Transformation Center.

- Raise up transformer tap.
- Lower transformer tap.
- Transformer regulator to automatic control.
- Transformer regulator to manual control.

F. Signals sent to the ROCP

Information generated by the automatism is written in the corresponding communication channel, for its processing and dispatch, via series, to the ROCP.

- Voltage level indication (Lower voltage / Normal voltage). Only for HV/MV transformers.
- LTCC function activated.
- Failure in LTCC function.

The last signal includes different anomalies that deactivate the LTCC function:

- Failure by unsuccessful command.
- Error in the configuration of LTCC functions.
- Failure, when the highest difference between taps is reached. Only for different transformers working in parallel

G. Modifiable parameters

System parameters wich can only be modified locally by the maintenance personnel.

- Delay time to generate the failure by unsuccessful command.
- Delay time to generate the failure, when the highest difference between taps is reached.
- Number of LTCC functions equipped: This parameter indicates how many of the eight functions available will be used in a RTU. It should agree with the number of transformers existing in that Transformation Center.

H. Internal signals

In order to make easier its supervision and first starting, the automatism has been equipped with internal signals that can be displayed “on line”. These signals will allow the technician to follow easily the automatism operation and state. Among others:

- Status: When automatism is running, this signal indicates the state where the programme is.
- Stop: It indicates why the automatism has been deactivated.
- Type: This signal indicates the type of transformer wich is controlled by each LTCC function.

6. Conclusion

The developed automatism has been designed as a modular system. So, it can be applied to different Transformation Centers configurations by adjusting its particular characteristic parameters. If necessary, it also allows to include more advanced remote supervision and control functions.

The Remote Control System for Transformers with On-Load Tap Changer presented in this communication is able to control a maximum of eight transformers. Also, it allows to particularize its operation to the following transformers types:

- High Voltage / Medium Voltage transformers.
- High Voltage / High Voltage transformers.
- Independent and no independent transformers.
- Equal or different transformers working in parallel.

Besides, the system has been equipped with the necessary subroutines to make an exhaustive control of the process and verify its good performance. In addition to the possible failures in the hardware of the equipment or in the signal processing, this automatism will verify the fulfillment of all generated commands.

The implementation of this automatism will be carried out taking advantage of the modular and variable configuration of these remote units. So, by doing an appropriate change in the software and a small hardware

upgrade, this goal can be achieved. In this way, the remote units will be able to carry out these additional automatisms autonomously. Besides, they can continue achieving all the telecontrol functions that were developing previously.

Finally, the main advantages of the solution presented in this work can be resumed as follow:

- It does not need a great investment because the automatism will be implemented in existent hardware. So, only some small modifications have to be done.

- It reduces the number of outages that the users could suffer unnecessarily and improves the quality of the electrical supply. In other words, it contributes to provide an important improvement in the power system control and operation.

Abbreviations

CT	Transformation Center
LTC	On-Load Tap Changer
RCS	Remote Control System
LTCC	On-Load Tap Changer Control automatism
ROCP	Remote Operation Control Position
RTU	Remote Terminal Unit
CPU	Central Processing Unit
DI	Digital Input card
DO	Digital Output card
AI	Analogic Input card
AO	Analogic Output card
HV/MV	High Voltage / Medium Voltage
HV/HV	High Voltage / High Voltage

References

[1] J.H. Choi and L.C. Kim, "The online voltage control of ULTC transformer for distribution voltage regulation", International Journal of Electrical Power and Energy Systems, Vol. 23, No. 2, pp 91-98, February 2001.

[2] R.B. Prada, B. Seelig, J. Dos Santos, L. Pilotto and A. Bianco, "Modelling On-Load Tap Changer Voltage Control and Limits for Network Loading and Voltage Control Effectiveness Assessment", in Proc. 2003 IEEE Bologna Power Tech Conference.

[3] C.J. Parker, I.F. Morrison and D Sutanto, "Simulation of load shedding as a corrective action against voltage collapse", Electric Power System Research, Vol. 46, No. 3, pp 235-241, September 1998.

[4] F.G. Montoya, A. Espín, F. Aznar, C. Gil and R. Baños, "Nuevo método para la optimización de tensión en redes de distribución utilizando técnicas de optimización evolutiva", in Proc. 8º Congresso Luso Espanhol de Engenharia Electrotécnica (CLEEE), Vilamoura (Portugal), July 2003.

[5] B. Otomega, V. Sermanson and T. Van Cutsem, "Reverse-Logic Control of Load Tap Changers in Emergency Voltage Conditions", in Proc. 2003 IEEE Bologna Power Tech Conference.

[6] C.D. Vourtanas and G.A. Manos, "Emergency Tap-Blocking to Prevent Voltage Collapse", in Proc. 2001 IEEE Porto Power Tech Conference.

[7] B. Kasztenny, E. Rosolowski, J. Izykowski, M. Saha and B. Hillstrom, "Fuzzy logic controller for on-load transformer tap changer", IEEE Trans. On Power Delivery, Vol. 13, No. 1, pp 164-170, January 1998.

[8] N. Yorino, M. Danyoshi and M. Kitagawa, "Interaction among multiple controls in tap change under load transformers", IEEE Trans. On Power Systems, Vol. 12, No. 1, pp 430-435, February 1997.

[9] P.J. Kang and D. Birtwhistle, "Condition assessment of power transformer on-load tap-changers using wavelet analysis", IEEE Trans. On Power Delivery, Vol. 16, No. 3, pp 394-400, July 2001.

[10] TEAM, Manual de uso. SISTEAM A. Hardware. Sistemas integrados de Control y Regulación de Procesos, Información Técnica ITSA, Bilbao.

[11] TEAM, Manual de uso. SISTEAM A. Software. Sistemas integrados de Control y Regulación de Procesos, Información Técnica ITSA, Bilbao.