A Wide Area Network for Data Acquisition and Real-time Control of the Cameroon Power System

Emmanuel Tanyi* **and Edwin Mbinkar****

Automation and Control Laboratory,
ECOLE NATIONALE SUPERIEURE POLYTECHNIQUE (ENSP),
University of Yaounde 1
(Web site: http://www.polytechcm.org)
(e-mail: emmantanyi@yahoo.com and **mbinkaren@yahoo.fr (Corresponding Author))*

Abstract: As part of the on-going deregulation of the electricity sector in Cameroon, the Electricity Development Corporation (EDC) is exploring the application of Information Technology as support systems to power system operation. Such IT-based corporate business strategies have the twin-objective of quality enhancement and cost reduction. Both power and service qualities are enhanced while both the operation and maintenance costs are reduced.
This is the context of, and motivation for, the research project described in this paper. The project involves the development of a Wide Area Monitoring System which can significantly improve grid utilization during phases of peak transmission demand while enabling the detection of critical factors influencing network stability. The monitoring applications also significantly reduce investment cost for utilities while safeguarding high levels of dynamic grid loading and availability. The integration of mobile agents, data acquisition systems and high performance communication networks endows the system with an adaptive protection capability as well as real-time automatic power restoration procedures.

Keywords: Mobile Agents, Data Acquisition System, Substation Control System, Power System, PSGuard, Phasor Measurement Unit.

1. INTRODUCTION

The increasing complexity of the Cameroon power system, with the integration of multiple geographically distributed generation sources in the grid, makes it difficult to deliver quality electricity supply to the ten regions of the country. In addition to this, the total installed capacity is far less than current peak demand of electric power in the country. As a result of this shortage, the power utility is increasingly trying to deliver the same total amount of energy to an increasing number of energy consumers, using existing system facilities, thereby putting the system under considerable strain. When transmission networks become overly strained, cascading failures become likely, (Hines, Hamilton, Feliachi et al. 2007). Since massive investment in transmission lines is extremely difficult, the industry will have to use the existing infrastructure more judiciously to meet the increasing demand for long distance power transmission.

Accordingly, many technical and economic issues arise, for example, all or some transient instability, insufficient reactive power supply, and even voltage collapse problems may coexist. This situation introduces the requirement for comprehensive analytical tools to assess the system security conditions, as well as to provide optimal control strategies to overcome these problems. A number of technologies have been proposed. Many utilities operate special protection, or remedial action schemes in which a control system is designed to react to extreme events by quickly enacting predetermined sets of control actions-typically demand and generation reduction, (Hines, Hamilton, Feliachi et al. 2007).

There is the growing need for the use of advanced controllers and data acquisition systems for the Cameroon power system. Such controllers and data acquisition systems will permit the reliable operation of the power system closer to its capacity constraints. This paper proposes an approach for interfacing a commercially available rapid controller to a Wide Area Network. The prerequisite for implementing this kind of controller is an efficient communication network, not only for supervisory control and data acquisition (SCADA) and energy management systems (EMS), but also for providing the protection, maintenance and planning departments with direct access to information from remote substation primary and secondary equipment.

The challenges to the development of this kind of control strategy are many and varied. Expectations for security of supply are becoming more stringent, and the control system has to play a big role. Secondly, services will in the near future be based on markets that involve transmission system operators (TSOs), as well as generation and distribution companies. Such systems will require timely, accurate and secure communication subsystems. More interconnection between systems will bring about an increased risk that faults will propagate from one system to another; therefore as power systems tend to depend increasingly on communications links, it will be crucial that problems with the communication network do not have effects on the power system, and vice versa.

This paper describes the conceptual design, and some illustrative design details, for a network of software agents with the ability to implement real-time control tasks that require more intelligence than simple protection schemes. The multi-agent approach has become the most promising method to build complex software systems, (Shant, Afaneen & Ahmed 2006). While there is no standard definition of an agent (or software agent), the concept is typically used to refer to software components that have their own thread of control (and hence may act autonomously), and are capable of sensing and reacting to changes in some environment (Buse & Wu 2007). This paper applies the concept to the coordination of communication between various entities of the real-time control system.

2. NETWORK - BASED POWER SYSTEM CONTROL

The current substation control systems in the Southern Interconnected Network of the Cameroon Power system have a number of drawbacks. The interoperability of devices is hampered by incompatible hardware interfaces and protocols and more access to substation information is required in order to make important decisions, (Woodward & Tao 2000). In recent years, a number of new architectures and products have been proposed which aim at addressing one or more of these drawbacks. In particular, there has been a proposal to integrate Local Area Networks (LANs), (Tanyi, Tsochounie, Nkenlefack & Noulamo 2005). This enables the system to use standard Ethernet networks and the TCP/IP internet protocol suite.

The use of Ethernet and TCP/IP in a power system has the important advantage that it allows the control system to be connected directly to the office and enterprise networks, which themselves usually use Ethernet and TCP/IP.

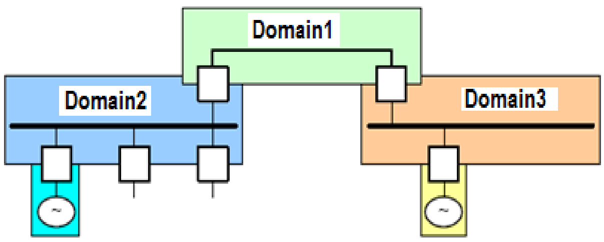

Fig. 1: Simple Multicast Domain Partitioning Example

Consequently, data collected by the control system can be shared with other systems such as databases and Enterprise Resource Planning (ERP) systems (Buse & Wu 2007), and can be viewed by users who are not located onsite. It is also possible to make network information accessible over the World Wide Web, which eliminates the need for a specific client program to be installed on a user's system as data can be viewed with a web browser. However, when a web browser is used, it is still necessary to download a large software component to the user's computer to allow online monitoring data to be displayed.

Given the scalable nature, speed, and complexity of modern Ethernet networks, network management can grow to become a major obstacle. A variety of standard tools are available to accomplish this task. Partitioning multicast traffic and limiting it to individual "Multicast Domains" can optimize system performance, (Veselin & Armando 2004). Partitioning can be achieved in different ways, and IGMP (Internet Group Multicast Protocol) is one of the most efficient methods. IGMP was originally developed for router-based communications. It allows individual Ethernet devices to form, join, and leave various multicast groups at will. A theoretical example of multicast domain partitioning showing multicast domains that are conveniently arranged to reflect the individual protection zone coverage is given in Figure 1.

All the computers in this communication network are placed in the same workgroup. A workgroup is a group of computers in a network that share resources, like files without a dedicated server (Microsoft 2001). However, each user has to have a user account on each computer to be accessed. Consequently, users in each block of Figure 1 are placed in the same domain. In this case a user can access network resources using any computer in the domain from one user account and one password.

3. THE SOUTHERN INTERCONNECTED NETWORK

The Cameroon power system is made up of the Southern Interconnected Network, the Northern Interconnected Network and the Eastern Network as separate entities. The Southern Interconnected Network has 29 substations, 2 hydro power stations, 4 heavy fuel oil thermal power plants and 5 light oil (diesel) thermal plants. Its total installed capacity is 1028 MVA accounting for 91% of the total energy, with transmission lines of up to 484Km for the high voltage network (225kV and 90kV).

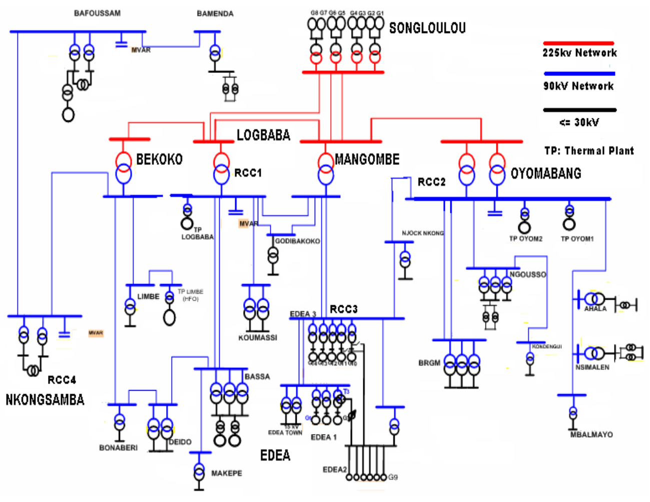

Fig. 2: Single Line Diagram of the Southern Interconnected Network

Supervision and control of all the operations in the Southern Interconnected Network is done in the control room at the grid dispatch center in Mangombe, using two SCADA systems.

The communication system is mainly made up of Power Line Carrier (PLC), UHF/VHF and microwave radio links; and some optical fiber links are currently being installed. Figure 2 above shows the single line diagram of the Southern Interconnected Network.

4. ARCHITECTURE OF THE DATA ACQUISITION AND REAL – TIME CONTROL SYSTEM

4.1 The Wide Area Network

In the proposed architecture, the information about the state of the network and control signals is carried by geographically distributed mobile agents located in a number of Intelligent Electrical Devices (IEDs). An IED is a hardware environment that has the necessary computational, communication and other input/output capabilities needed to support a software agent, (Shant, Afaneen & Ahmed 2006). These agent based IEDs work in an autonomous manner where they interact both in their environment and with each other, and can interface with legacy systems such as SCADA. A mobile agent is a computer software program with the capability to suspend its execution and resume it on another computer (Buse & Wu 2007), (Douglas & Steven 2001). Some of the benefits of the multi-agent systems approach are cited in the literature, (Douglas & Steven 2001). In the context of real-time control of power systems, they have been proven:

i) To address problems that are too large for a centralized single agent, for example because of resource limitations or for robustness concerns (the ability to recover from fault conditions or unexpected events) in power systems;

ii) To allow for interconnection and interoperation of multiple network systems, e.g. expert systems, decision support systems, legacy network protocols such as TCP/IP;

iii) To improve scalability – the organizational structure of the agents can dynamically change to reflect the dynamic environment, i.e. as the network grows in size the agent organization can re-structure by agents altering their roles, beliefs, and actions that they perform;

iv) To provide solutions to inherently distributed problems, such as real-time control of interconnected power systems;

v) To provide solutions which draw from distributed information sources like the IEDs; and

vi) To provide solutions where the expertise is distributed.

The traditional way of transmitting information in this system is that the information will be sent from/to the RTUs (Remote Terminal Units) in each substation from/to the RCCs (Regional Control Centers), then from/to the Southern Network Control Center (SNCC) in Mangombe which serves as the load dispatch center. The proposed architecture has the ability to sense automatically any disturbance such as the separation of a transmission line, a unit generation of any generation station and the separation of a whole station by the RTUs. The RTUs contain the IEDs and ABB (a Swiss multinational company) has manufactured a commercial off-the-shelf product called PSGuard. The PSGuard is used for Wide Area Measurement, Monitoring, Protection and Control and provides state-of-the-art solutions for counteracting system instabilities and preventing power outages. It is designed to detect incipient abnormal system conditions and take counter actions to preserve system integrity and ascertain acceptable power system performance (ABB 2003).

PSGuard is the ABB solution for wide area monitoring, protection and control incorporating the latest technologies applied to identify instabilities in power systems and evaluate the most effective measures against large area disturbances. PSGuard system utilizes phasors, which are measured by synchronized Phasor Measurement Units (PMU) resulting in an accuracy of < 1 μs. A communication system links PMUs which are located in substations to the PSGuard system for data transmission, (Bertsch, Ingram, Broski et al. 2004). Data exchange can be established between PSGuard and other control and protection systems to allow for optimum data sharing and control actions.

Table 1. Delay Calculations Associated with Communication Links

Communication Link	Associated Delay (one – way) In milliseconds
Fiber Optic Cables	≈100 – 150
Digital Microwave Links	≈100 – 150
Power Line Carrier (PLC)	≈150 – 350
Telephone Lines	≈200 – 300
Satellite Link	≈500 - 700

The PMUs form part of local devices called System Protection Terminals (SPT). SPTs are able to run complete or parts of distributed control algorithms and can communicate directly with other SPTs, substation equipment and system protection centers (SPC), which are responsible for monitoring and control of the power grid. The PMU derives its inputs from the secondary sides of the three phases of a potential or current transformer and outputs the corresponding positive sequence voltage or current phasor, (Biju, Valenti, & Feliachi 2002). They measure voltage, current, and frequency phasors using the discrete Fourier transform (DFT) and can detect transients or surges within milliseconds of their occurrence, (Biju, Valenti, & Feliachi 2002). PMUs use the IEEE 1344 data format for communication with the central monitoring station (PSGuard). Biju, Valenti, & Feliachi (2002) have also calculated communication delays associated with different links as shown in Table 1.

Communication links used between the PMUs and the PSGuard can include both wired (telephone lines, optical fibers, power lines) and wireless (satellites) options. Delays associated with the link act as a crucial indicator to the amount of time-lag that takes place before action is initiated. The delays are an important aspect and should be incorporated into any power system design or analysis, as excess delays could ruin any control procedures adopted to stabilize the power grid.

4.2 The Database System

The proposed database is a distributed system incorporating a centralized database and other parallel databases. The centralized database consists of just a single machine, and the parallel databases consist of a cluster of machines (located at the major buses) with the same hardware configuration as the machine in the centralized database, (MIT 2005, open courseware). The IEEE 1344-1995 is a standard for synchronized phasor measurements in substations, (Martin, Benmouyal, Adamiak et al. 1998). Phase angles between sites can be determined when the measurements are synchronized to a common time source. The standard describes the measurements in relation to a PMU. It addresses synchronization of data sampling, data-to-phasor conversions, and formats for timing input and phasor data time, accuracy, hardware, software, or a phasor computation process. The PMU transmits messages (according to the IEEE 1344 format) in three types of frames as discussed below.

i) Data frame: The data frame provides information regarding phasor data and the state of the digital inputs on each channel. It also defines the trigger status of frequency, angle, over-current, under-voltage and rate of frequency change.

ii) Header frame: The header frame is an ASCII file that contains identification information about the PMU, data source, algorithms, and the analog filters used.

iii) Configuration frame: This is a machine-readable binary file that contains PMU identification code, number of phasors, number of digital channels, channel and phasor names, nominal line frequency, and the transmission period of the phasors.

The PMU also receives messages that indicate when to start or stop the transmission of data. The data format for this primarily consists of the time stamp and the command code, which informs the PMU of the action that needs to be taken.

There is a data search engine which is a directory-service-like information server. Instead of collecting all the data in the central database at the SNCC, the data center collects information indicating where and what data is available. The data search engine accepts user retrieval requests and routes the requests to proper data sources, which then return the requested data to the user directly or indirectly through the data center. The data that has been retrieved and returned to the data center enters the central database and is made available for future requests.

There is no need to move all the data from various data sources to the central database at once. To avoid massive storage requirements at the data center, only selective data is stored at the data center. Data selection can be done by some arbitrary rules (e.g., select data for a specific event) or by user data retrieval requests. In this way, the data storage at the data center will grow with time. In addition, this central database and the original data source are backup copies of each other.

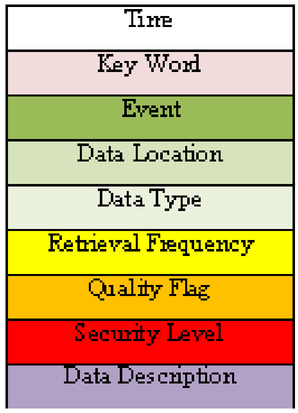

Fig. 3: Data Stamp Structure

The data stamp structure shown in Figure 3 above is associated with a specific data file and may include the following fields: time, key words, associated event, data location, data type, retrieval frequency, data quality flag, data security level, and data description. The fields of time, key words, associated event, data location and data description may help data search. A data file with a low data retrieval frequency for a certain amount of time is indicated as low-usage data and should be removed from the central database at the data center. Data security level is used for data access control, and data quality flag indicates how good the data is.

Data is acquired and initially stored by different RCCs at different locations as shown in Figure 4 below. Such data can be “plugged” into the archiving system and interdependency between data sources is eliminated. The data retrieval and archiving procedure is as follows:-

i) User initiates the procedure by sending a data request to the data search engine at the reliability organization data center.

ii) The data search engine either finds the data in the central database or routes the request to proper data sources. Note that the request can be routed to multiple data sources based on the contents of the request.

iii) If the requested data is available in the central database, the data center returns the data to the user.

iv) If the requested data is not available in the central database, the request is routed to appropriate data sources, and the data sources return the requested data to the data center. The data sources can also return data to the data user directly. Note that the data center can send out its own data requests to data sources as well.

v) The data center sends the data to the user and also keeps a copy in the central database as archive. The data center also logs the data transaction in its database.

vi) The user may save the requested data in its own local database.

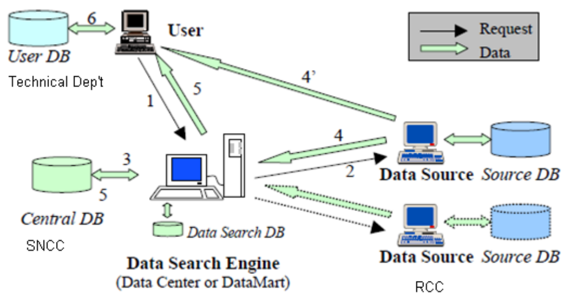

Fig. 4: Data Retrieval and Self-Evolving Data Archive

A variety of alternatives exist for synchronization of remote measurement units using a signal from a central location that has been sent to all the measurement units at the same time, (Saifur, Manisa & Yonael 2007). Among the available systems the following groups exist: AM radio broadcasts, Microwave transmission systems and Fiber-optic transmission systems. AM radio broadcasts are the least expensive, but due to a variety of problems with their implementation, their accuracy is very limited (to a few milliseconds). Both microwave and fiber-optic circuits require substantial hardware and maintenance investment while reaching the accuracies of 1 ms or better. It should also be noted that leased wire line circuits could also be used in place of microwave or fiber systems, (Biju, Valenti, & Feliachi 2002). However, the user generally has no control over long distance circuits. Routing changes, costs, and reliability combine to make this method undesirable.

Most utilities have different communication systems for each type of control (transmission SCADA, substation control system, distribution control system, load control, meter reading). The optical fiber is now making its way into the Cameroon market and all the Regions of the country are expected to be linked by optical fibers by the year 2015, (MINEPAT 2010). Considering the present technology, if a mobile agent needs data from more than one system, it will have to get it from the system's central database. This communication structure might limit the capabilities of agents that need to act quickly using only data from within one communication system.

4.3 Real-Time Control

The following typical sequence of actions would be initiated by PSGuard, if the power system approached instabilities, (Jim 2002), (Lohmann 2005).

i) Alerting the system operator by indication of the remaining safety margin ΔS and by providing on-line guidance to counteract a critical situation. In addition, corresponding information is produced for the EMS.

ii) Control actions are initiated if the safety margin ΔS reaches a pre-set critical level to avoid voltage instabilities to occur. Some of these actions include:

a) FACTS (Flexible AC Transmission System) can produce or consume reactive power. This action is instantaneous and in case of voltage collapses, it can counteract voltage instability following loss of several transmission lines.

b) LTC (Load Tap Changer control). If the load current increases LTC can raise the tap position to compensate for the voltage drop. In the course of severe power system disturbances this, however, would be a counterproductive action. Therefore, PSGuard blocks LTC or changes the set-point of the tap changer to preserve system stability.

c) AGC (Automated Generator Control). Objectives of AGC are to regulate frequency and to maintain balance of power. It controls the load reference set-points of a group of generators, and is confined to a single area.

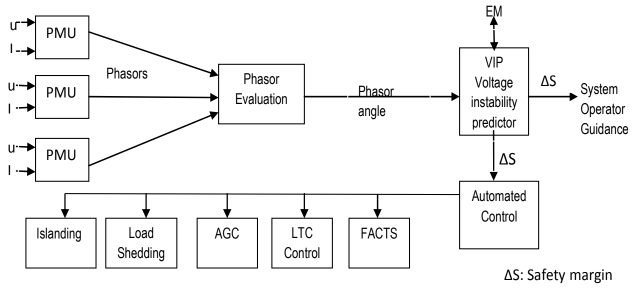

Fig. 5: Responses to Power System Instabilities

d) Load shedding. This is necessary in case of under-frequency initiated to minimize the risk of system collapse, and when under-voltage is initiated to preserve system stability. In any case, load shedding should be conducted before islanding is initiated.

e) Islanding. This is the last defense measure towards saving the power system. It can only be applied if specific load/generation areas can be defined.

The block diagram in Figure 5 shows the interaction between the various applications. Central to this topology is an open source SCADA that will enable physical and software components to communicate with each other, as well as the distribution utility, (Jim 2002). This is built upon the multi agent concept that is incorporated in TCP/IP network.

5. APPLICATION TO THE SOUTHERN INTERCONNECTED NETWORK

Figure 4 shows the database system with computers at the nodes. From Figure 6, it can be seen that the system uses geographically distributed PMUs located at the major buses. The SNCC which is also the load dispatch center is responsible for monitoring and controlling the whole electrical network through the Regional Control Centers (RCCs). The RCCs located at the major generation points and at major substations (Logbaba, Oyomabang, Edea, Nkongsamba, etc.) are responsible for monitoring and controlling the electrical network in a particular region. The detection of any abnormal condition is passed to the

Distribution Control Centers (DCCs) which can share information to give orders to the control and protection devices to overcome the problem automatically.

Phasors measured throughout the interconnected grid require a common timing reference provided by a synchronizing source, (IEEE Standards Board 2001). The synchronizing source may be local or global, and the signal may be distributed by broadcast or direct connection. The signal provided by the synchronizing source is referenced to Coordinated Universal Time (UTC). It provides enough time information to determine second-of-century in agreement with UTC. The synchronizing signal has a basic repetition rate of 1 pulse per second (1 PPS) with a stability of at least 1E- 07. The synchronizing signal is always available without interruption at all measurement locations throughout the interconnected grid. Its reliability exceeds 99.87% (1 h of outage per month), (IEEE Standards Board 2001), (Martin, Benmouyal, Adamiak et al. 1998). The signal is accurate enough to allow the PMU to maintain synchronism within 1ms of UTC including both synchronizing source and local receiving equipment error.

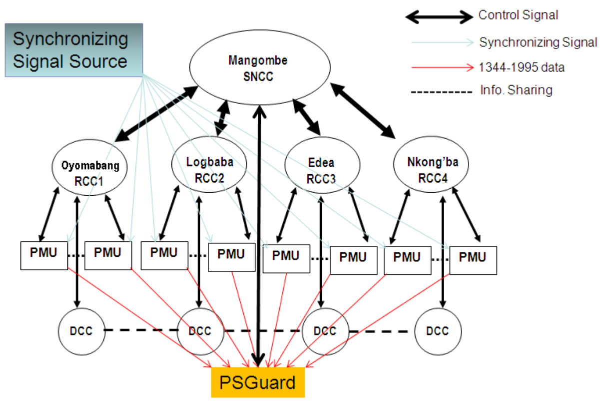

Fig. 6: Architecture for the Implementation of the Wide Area Communication and Control Scheme.

6. CONCLUSION AND FURTHER WORK

6.1 Conclusion

A Wide Area Network for data acquisition and real-time control has been designed and applied to the Southern Interconnected Network of the Cameroon power system. The network is structured into a four-level hierarchy with the Southern Network Control Center (SNCC) at the highest level, Regional Control Centers (RCCs) at the secondary level, Phasor Measurement Units (PMUs), monitoring major bus bars, at the tertiary level and Distribution Control Centers (DCCs) at the lowest level.

The main software components of the system include Mobile Agents and a Distributed Database. The software architecture enables the integration of service and network management. The use of latest developments in distributed computing theory renders the systems very reliable as the communications network does not affect the power system. Consequently, failure in the communication system does not immediately lead to failure in the power system and vice versa.

6.2 Further Work

Three main problems still have to be addressed in this research project. The first problem is the upgrading and standardization of some of the communication subsystems. The communication system which preceded the Wide Area Network was designed and installed in an ad-hoc manner and it contained a multiplicity of both analog and digital technologies. Although most of these outdated technologies were decommissioned, in critical nodes of the network, before deploying the Wide Area Network, some of the technologies are still being used in other parts of the network. This poses a problem of standardization. All components of the communication system have to conform to the IEEE SCC21 1547 series of standards concerning smart grids.

The second problem is that of data security. There are many levels of access. The Network Operator has the highest level of access which allows all of the system data to be retrieved. However, the companies providing network services must be given lower levels of access which prevent them from having sensitive information about other companies. This guarantees fair competition and a level playing ground for all companies.

The third problem is the monitoring and evaluation of the performance of the distributed and hierarchical real-time control system. The performance of all subsystems must be assessed, including the Southern Network Control Center (SNCC), the Wide Area Network, the Regional Control Centers (RCCs) and the Distribution Control Centers (DCCs).

The progress made with these different aspects of the project will be reported in subsequent publications.

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