PORTABLE VOLTAGE REGULATOR FOR LOW VOLTAGE NETWORKS

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ABSTRACT

This paper describes the development of a Portable Voltage Regulator for Low Voltage Networks (PVRLVN) that aims at maintaining consumers feeding voltage within the limits set by Brazilian regulations. PVRLVN allows adjusting the input voltage by means of the addition or subtraction of the adequate amount of voltage so that output voltage is within an adequate level. Power control is carried out based on static switches and repairers, all controlled by a microprocessor.

The developed regulator was installed in an actual network of the AES-Eletropaulo, a local Brazilian Distribution System Operator (DSO). Tests and results obtained are presented and discussed.

INTRODUCTION

Currently , consumers existing in the distribution networks and regulatory agencies are constantly concerned with the adequate voltage level offered by DSO companies. In Brazil, ANEEL (Brazilian Electricity Regulatory Agency), has created the PRODIST (Distribution Procedures)[1] where the rights of consumers to request to power distributors the measure and assessment of power level when it is out of the preset regulated limits is consolidated.

Due to several reasons, it may occur that some consumers who are connected to the power net be subject to voltage levels that are outside the mandatory level deemed suitable. In such cases, concessionaires are forced to identify the problem at a term set by ANEEL. Depending on the intervention carried out to solve the issue, the term set is not enough to solve the event that caused the problem.

For the utility to be able solve the voltage problem of the consumer as fast as possible, while it prepares a more complete intervention in the network (redistribution of load or change of conductors of the network, etc.) it may use the Portable Voltage Regulator for Low Voltage Networks (PVRLVN) proposed immediately after the acknowledgment of the voltage issue.

The PVRLVN developed in this survey presents the following characteristics: power of 30KVA, voltage of 115V+115V (phase-neutral) and frequency of 60Hz. A significant feature of the PVRLVN is its portability, as it may be installed at a pole close to consumers facing problems with voltage level. The equipment was projected and tested on laboratories and in the field to operate as a temporary equipment that should feed the consumers until a permanent solution is adopted by the DSO.

PORTABLE VOLTAGE REGULATOR

The developed Voltage Regulator performs its function to adjust the tension of the not regulated network applied on its entrance by means of the addition or subtraction of a suitable amount of voltage that is inserted through a secondary of the Buck-Boost transformer, allowing that at its exit, on load, the voltage remains within the range set forth by ANEEL.

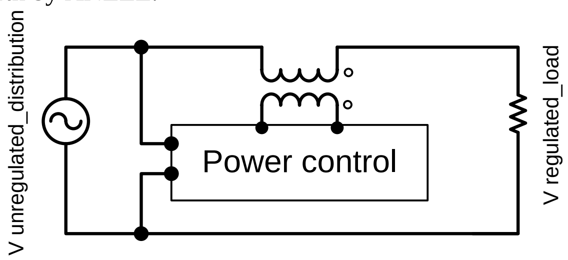

Figure 1 – Basic circuit of the voltage regulator

Figure 1 shows the basic circuit of the voltage regulator where the voltage of input network (represented by the voltage generator Vunregulated_distribution) is applied at the entry of the regulator that is composed by the power control circuit plus a Buck-Boost transformer that deliver to the load connected to the exit the voltage duly regulated within the range set forth by ANEEL.

Power control allows three basic actions at the incoming voltage:

a) to add voltage to income voltage, while income voltage is bellow the lower limit set forth as the minimum accepted.

a) to subtract voltage to income voltage, while income voltage is above the lower limit set forth as the higher accepted.

c) not add nor subtract voltage to income voltage when income voltage is within the range set forth as suitable.

Aside from controlling the polarity of the voltage of the buck-boost transformer, the regulator controls the amount that is added or subtracted at the income voltage of the regulator. In the event of the PVRLVN afore mentioned, the power control allows five different levels of regulation of the network voltage, as follows:

1) voltage of very low network => sum "a lot",

2) voltage of very low network => sum "little",

3) voltage of a regular network => does not add nor subtract,

4) voltage of high network => subtract "little",
5) voltage of very high network => subtract "a lot",

PVRLVN Operation Principles

The PVRLVN Buck-Boost transformer is used to add and subtract amounts as previously described through two daps on primary, being its secondary divided into two windings, as the electric design shown in Figure 2.

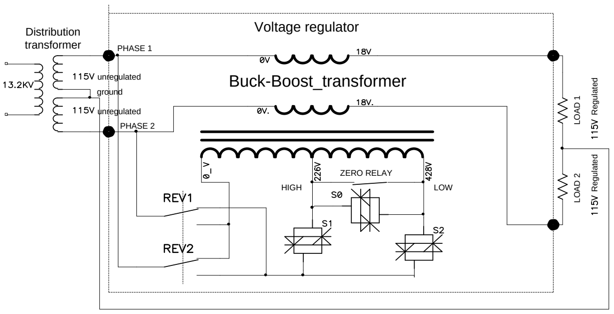

Figure 2 – Developed PVRLVN electric design.

The distribution transformer, shown in Figure 2 is not a part of the regulator (dashed line) but it rather belongs to the distribution line of the power concessionaire. The regulator was projected to be connected to the secondary of the distribution transformer of a supply system whose secondary network is monophase of (115V + 115V / 230V). Each secondary winding of 18V of the Buck-Boost transformer regulates individually each phase of 115V (Phase-Neutral) of the distribution transformer. Load receives voltage regulated between Phase 1 and neutral and Phase 2 and neutral, as Figure 2. The neutral of the distribution network is directly connected to the exit, without going through the equipment.

The S0, S1 and S2 switch are formed by 2 SCRs in anti-parallel (AC_Switch) and its command is done through a driver plate with wrist transformers on the respective gates. The polarity reverser contactor is used to invert the polarity of the primary of the Buck-Boost transformer aiming at adding voltage in an event or subtract voltage in another event a so adjusting the output to keep within the range demanded by PRODIST. The contact of the zero relay (NC) is used to ensure zero voltage in the secondary of the regulator at regulator startup. The zero relay moves to a safe position not introducing (adding or subtracting) any value at the network voltage.

Voltage regulation is obtained through the activation of the static switches that operate according to the state machine shown in Figure 3 and respective Table (Table 1). Output tension regulation follows the state sequence predefined by the state machine and the tap change is done in such manner as to keep the output voltage within the range 110V and 120V, values of neutral stage voltage. The voltage to be regulated is the effective output voltage at a steady state and the reading interval of this voltage is ten minutes, according to the regulation. Operation time for changes of static switches taps was set in 5 seconds, deemed enough so as to avoid successive switching due to repetitive changes of load voltages.

Transformation relations of Buck-Boost transformer were defined as follows.

1) Output voltage limits are set first, as required by PRODIST, as is the case in this project: lower limit 0,94 pu and higher limit 1,05 pu.

2) The transformation relations related to the income voltage values range, keeping the values range of the output voltage constant (Figure 4) as follows:

i. To the income voltage 0,94 pu < Vincome < 1,05 pu, the turns ratio is $k_1 = 1$. Here the output voltage is Voutput $= k_1$ x Vinput , operation on the inclined line k_1,

ii. Operating on the inclination line k_1 , when income voltage V_{Entry} < 0,94 pu, the output voltage should be taken to 1,05. In this case, the turns ratio between the output and input is $k_a = 1{,}117$. Here the output voltage is Voutput $= k_a$ x Vinput , operation on the inclined line k_a,

iii. While operating on the inclination line k_a , the lower limit of income voltage that corresponds to the lower limit of the output voltage is $V_{income\_lower\ limit\_ka} = 0{,}94/\ k_a$,so $_{income\_lower\ limit\_ka} = 0{,}842$,

iv. Operating on the inclination line k_a , when income voltage V_{Entry} < 0,842 pu, the output voltage should be taken to 1,05. In this case, the turns ratio between the output and input is $k_b = 1{,}2477$. Here the output voltage is Voutput $= k_b$ x Vinput , operation on the inclined line k_b,

v. While operating on the inclination line k_b , the lower limit of income voltage that corresponds to the lower limit of the output voltage is $V_{income\_lower\ limit\_}k_b = 0{,}94/\ k_a$,so $_{income\_lower\ limit\_}k_b = 0{,}753$,

vi. Operating on the inclination line k_1 , when income voltage V_{Entry} < 1,05 pu, the output voltage should be taken to 0,94 pu.In this case, the turns ratio between the output and input is $k_c = 0{,}895$. Here the output voltage is Voutput $= k_b$ x Vinput , operation on the inclined line k_c,

vii. While operating on the inclination line $_{kc}$, the higher limit of income voltage that corresponds to the higher limit of the output voltage is $V_{income\_higher\ limit\_kc} = 1{,}05/\ _{kc}$,so $_{income\_higher\ limit\_}kc = 1{,}173$,

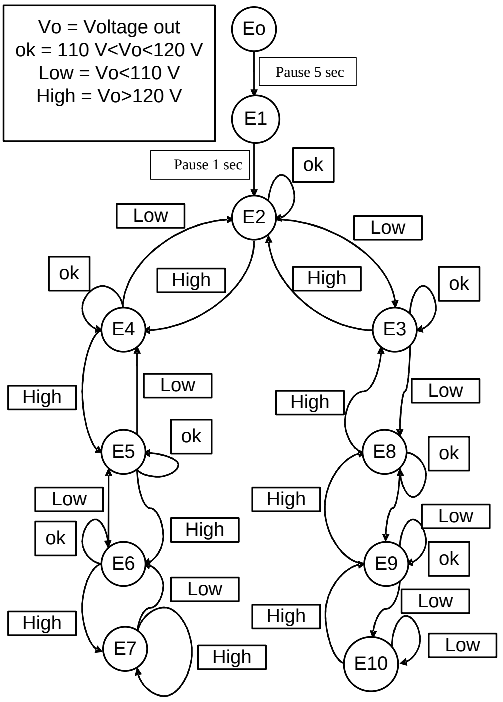

Figure 3 – State Machine of PVRLVN voltage control

Table 1 - PVRLVN Voltage Control States

Status	Name of Status	Status Description	Switches Status
E0	Power_ON	Wait 5 sec after powering	00000000(*)
E1	Sum zero	Wait 1 sec.	00000001(*)
E2	Sum or Subtract	If 110V<Vo<120V Keeps in E2 if status does not change	00010001(*)
E3	Sum zero	If 110V<Vo<120V Keeps in E3 if status does not change	00110001(*)
E4	Low sum	If 110V<Vo<120V Keeps in E4 if status does not change	00010001(*)
E5	Subtracts little	If 110V<Vo<120V Keeps in E5 if status does not change	00010100(*)
E6	Subtracts a lot	If 110V<Vo<120V Keeps in E6 if status does not change	00011000(*)
E7	Outgoing over voltage	Overvoltage warning	00011000(*)
E8	Low sum	If 110V<Vo<120V Keeps in E8 if status does not change	00110100(*)
E9	Sums a lot	If 110V<Vo<120V Keeps in E9 if status does not change	00111000(*)
E10	Output voltage	Subvoltage warning	00111000(*)

(*)Byte Switches = x, x, REV, RZ, S1, S2, x, S0, when = 1 on and = 0 off, where : Bit7 = x Nothing connected ; Bit6 = x Nothing connected ; Bit5 = REV = reversion contactor ; Bit4 = RZ = Relay zero; Bit3 = S1= switch 1; Bit3 = S1= switch 2; Bit6 = x Nothing connected ; Bit0 = S0 = Switch 0

viii. Operating on the inclination line k_c , when income voltage V_{Entry} < 1,173 pu, turns ratio between output tension should be taken to 0,94 pu. In this case, the turns ratio between the output and input is k_d = 0,802. Here the output voltage is Voutput = k_d x Vinput , operation on the inclined line k_d,

ix. While operating on the inclination line k_d , the higher limit of income voltage that corresponds to the higher limit of the output voltage is $V_{income\_higher\ limit\_}kd$ = 1,173/ k_d ,so $_{income\_higher\ limit\_}k_d$= 1,310,

Figure 4 presents the transfer function between the Input and Output Voltage of PVRLVN that was used to estimate taps voltage of Buck-Boost transformer, setting on the vertical axis (output voltage in pu) the range demanded by PRODIST, that is , -6% and +5% . It may also be seen in this Figure 4 the income voltage range of -25% to +30% where PVRLVN is able to regulate output voltage.

One can see in the annex two Figures of the developed PVRLVN equipment.

TESTS

Tests were carried out to check the performance of the regulator in conditions of permanent load when income voltage was within the range of 180 V to 270 V and verify whether the output voltage remained within the range demanded by PRODIST. Other purpose of tests was to obtain the output characteristic, transfer function between output and input voltage of the regulator in normal operation. For the voltage regulation tests were considered 3 load conditions.

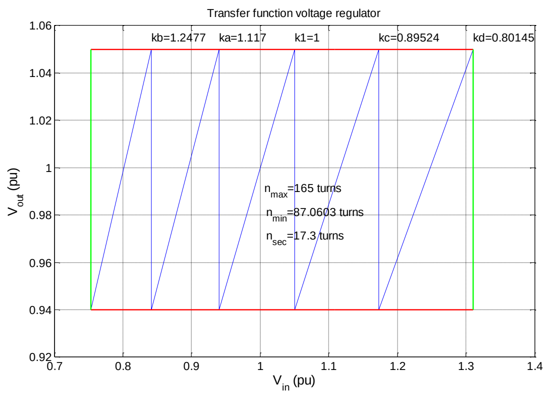

Figure 4 – PVRLVN transfer function

During tests, were recorded voltages and currents at the entry and exit of the regulator. Voltage value records and current were made at 1 s. intervals. Voltage at regulator entry was altered by means of the adjustment of exciting of a synchronous 50 kVA generator operated by diesel oil engine.

Table 2 shows a summary of the results between exit and entry voltages obtained in the three tests related to approximate loads for all tests.

To all tests carried out, regardless the load present in the voltage regulator, results show that the suitable voltage range at the regulator exit was kept within the limits, between 220 V and 240 V, for voltages at the entry varying at a range between 188 V to 275 V, that has guaranteed for the prototype of the developed regulator a satisfactory performance.

Table 2 – Income and Output voltage amounts obtained in tests for assessing the voltage regulation.

Voltage (V) – Test with Load					
18 %		58 %		90 %	
Entry	Exit	Entry	Exit	Entry	Exit
189	223	186	218	188	219
203	222	200	234	209	227
220	220	220	220	214	214
246	224	229	226	231	226
264	240	216	235	252	228
270	220	257	234	273	219

RESULTS

At the end of the development of the PVRLVN DSO AES-Eletropaulo has used it in an actual event of voltage claim. At the chosen site the network voltage presented, during parts of the day, levels of voltage out of the suitable range, causing a daily penalty of USD 2,350.00. PVRLVN was installed and took over the load of 14 consumers who were at the end of a distribution feeder with voltage problems. For the event in screen, the voltage curves at consumer's entry and exit are seen in Figure 5.

PVRLVN has a protection at the primary circuit that turns off the PVRLVN control in case of short circuit and sets the PVRLVN in state of safe failure (does not add or subtract voltage to voltage of regulator entry). With this protection, consumer is never disconnected by PVRLVN, rather its control circuit being disconnected.

The use of PVRLVN in filed showed the need for implementing an automatic reconnection system for the event of operation of the protection of the primary circuit of the Buck-Boost transformer. Implemented circuit reconnects the PVRLVN five times in case failure persists and keeps light warning of protection operation. This reconnection system provides the equipment more operation autonomy, avoiding eventual failures to remove and keep PVRLVN off operation.

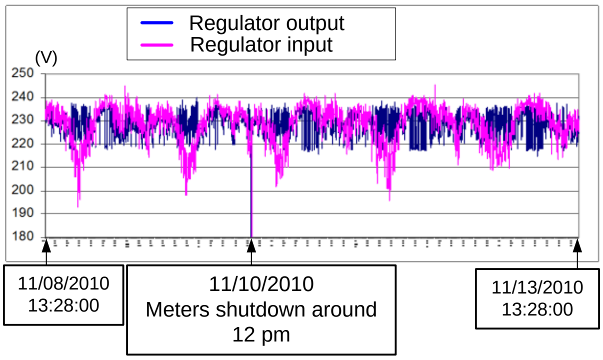

Figure 5 – Results of voltage measuring of entry and exit of PVRLVN in real situation.

CONCLUSIONS

Results of tests carried out during the development of the PVRLVN prototype allowed us to obtain a series of information that helped to accomplish its project detail and to obtain a satisfactory operation condition. As shown in the operation tests results of the regulator in controlled environment of voltage load and variation, the regulator prototype presented a fully satisfactory behavior, having met the aimed purposes.

Aside from the results in laboratory tests, the results obtained with the PVRLVN in installation and service to consumers in an actual situation have shown that the developed prototype has reached the expected results.

From the results of the projects, we made a patent request of the developed solution and started a new project to manufacture the device.

REFERENCES

[1] ANEEL, 2009, *PRODIST (Distribution Procedures of Electrical Energy in the National Electrical System)*, http://www.aneel.gov.br/area.cfm?idArea=82

[2] Saraiva Filho, Francisco da Costa, 2002, *Proposal of Dynamical Recuperator for Voltage Sags*. Author's Master Thesis, Polytechnical School of University of São Paulo http://www.teses.usp.br/teses/disponiveis/3/3143/tde-10052003-225059/pt-br.php

ANNEX 1

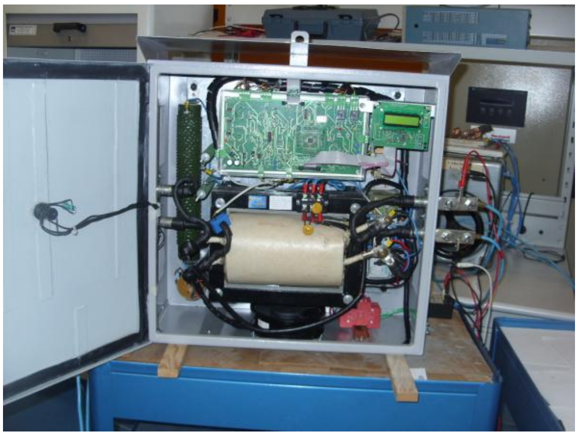

Figure a1 –PVRLVN in the Laboratory

Figure a2 –PVRLVN Installed at the Training Center of AES Eletropaulo