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Power Flow Management for a Smart Micro-Grid by using Power Electronics Transformer

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***Abstract*—A novel approach for control of the flow of power for a smart micro-grid. The smart micro-grid is a grouping of controllable loads and distributed energy resources (DER). Generally a 50/60 Hz, step-down transformer are used at the point of common coupling (PCC) to connect the main grid to the micro-grid. Substitute of the conventional transformer into PET. The PET transformer hence restores the system frequency by adjusting supply and demand at the PCC. The proposed PET transformer is a high frequency power converter system comprised of a high frequency step-down transformer and matrix converters three phase to single phase. The matrix converters are modulated with a new PWM strategy. Simulation results are verifying the operation of the Power electronics transformer.**

Keywords—Distributed energy resources, Power electronics transformer, Smart Micro-Grid.

I. INTRODUCTION

Today's sophisticated and smart technologies for consumer products make it necessary to encourage modernization for a current electric power generation transmission and distribution. For the varying customer requirements, new generation appliances and difficult working strategies challenge and security and feature of the power supply. By means of increasing complexity on the power grid, a new infrastructure that superior handles these changes in concern of the society, economics as well as situation is necessary. The micro-grid a newly emerging regulatory environment, connected to the power system grid. It is a group of distributed generations (DGs) and energy storage system. This DG technology consists of wind turbines, solar generators, micro turbines etc.

II. PROPOSED TECHNOLOGY

In the proposed technology, the conventional 50/60 Hz transformer is substituted by a active power limiter at the PCC, as shown below in figure:1,

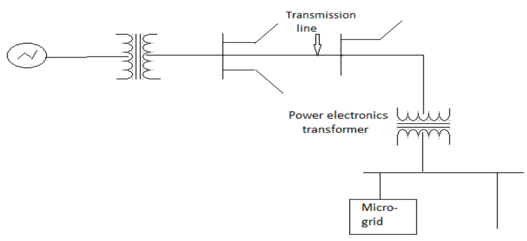

Fig.1. Three phase transmission and distribution network

By introducing power electronics transformer the active power flow from the power grid controlled at the PCC to a required value determined by utilities. Therefore, when the active power at the PCC increases further than a pre-set value, the power electronics transformer restricts the active power flow from the power system grid and thus resulting decrease in the grid frequency within the micro-grid; the grid frequency of the power system grid does not affected.

III. STATE OF THE ART

(A)Micro-grid

The interconnected electric power system network is vulnerable to grid failure frequently caused by unexpected natural phenomenon. In progress research in countries like, USA, Europe, Canada, Japan investigates best possible integration of distributed energy resources (DERs) in conventional power system network. The large amount of penetrations of DERs and their potential have increased study activity in the hence defined micro-grids to make certain reliable power supply to a definite group of consumers. The different components of a micro-grid, DGs, DSs, loads, interconnected switch etc. The micro-grid draw near promises the energy delivery and supply system to be Highly efficient, secured and reliable.

(B)Power electronics transformer

A power electronics transformer works at much higher frequencies, of the range of kHz. The power electronics transformer consists of a high frequency transformer with three phase to single phase matrix converter on its primary and secondary side as below shown in fig-2

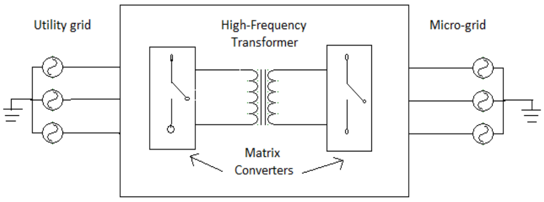

Fig.:-2. Power electronics transformer

The developed topology consists of two matrix converter with high frequency AC link. The primary terminal of electronic transformer is supplied by main grid and secondary side has the equivalent AC source of a micro-grid [3].

The three phase input voltage at the line frequency (50/60Hz) is changed into high frequency (10 kHz) single phase voltage by matrix converter. This yields high frequency pulsating single phase AC voltage at primary & secondary side of the high frequency transformer. The main grids define "the limit for the reference power for a particular micro-grid it serves at the PCC". The average active power as calculated at the output Ac source can thus be controlled. By determining the corresponding modulation signal for the secondary side matrix converter, the equivalent phase shift can be accomplished. The active power flow among the input side and output side of the power electronics transformer is regulated is same as that in a dual active bridge. The active power flow is controlled by regulating the phase shift among the primary and secondary voltages at the transformer. This is accomplished by a PI controller configured for the control signal of PWM scheme applied for matrix converter modulation. The gain parameters K_p and K_i of proportional and integral controller are designed to provide a faster response while reducing any steady state error.

(C) MATRIX CONVERTER

The power electronics transformer consists of matrix converter that contribute to the high frequency operation. The matrix converter uses insulate gate bipolar transistor (IGBT) bi-directional switches, with a switch joined among input face to output face. They supply a direct link among the input as well as the output, without any intermediate energy-storage component. A first solution difficulty is correlated to the bi-directional switches recognition. By definition, "a bi-directional switch is capable of conducting currents and blocking voltages of both polarities, depending on control actual signal". However at current time a bi-directional switch is not presented on the market. So it must be realized by the mixture of usual uni-directional semiconductor devices [4].

In a power electronics transformer proposed here consists of both side matrix converter, input side matrix converter and output side matrix converter.

a)INPUT SIDE MATRIX CONVERTER

The input-side matrix converter a shown in fig.-3 converts the three phase ac voltage to a high frequency one phase pulsating voltage at the transformer primary side.

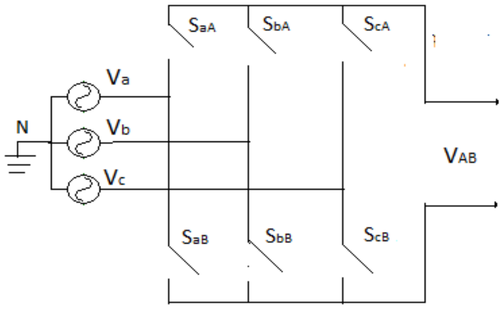

Fig.:-3. Three phase to one phase matrix converter

This is a straight link matrix converter through a established rectification period followed by a single phase inverter. The input line current as well as the input voltage is in phase. The matrix converter consists of six bi-directional IGBT switches. The Three phase sinusoidal input voltage supply, with peak value V_{in} and angular frequency ω_{in} is given by:

$$V_a(t) = V_{in}\cos(\omega_{in} t)$$

$$V_b(t) = V_{in}\cos(\omega_{in} t - \frac{2\pi}{3})$$

$$V_c(t) = V_{in}\cos(\omega_{in} t + \frac{2\pi}{3})$$

The single phase pulsating output voltage is given by V_{AB}. The matrix converter has 6 bi-directional switches indicated by S_{aA}, S_{bA} and S_{cA} corresponding to output phase A and S_{aB}, S_{bB} and S_{cB} corresponding to output phase B .

The duty ratios of the switches are a function of $k_A(t)$ & $k_B(t)$ which are time varying signals with required output frequency $F_s = \frac{1}{T_s}$, is given by.

$$k_A(t) = +k_i \qquad 0 \le t \le T_s$$

$$= -k_i \qquad T_s \le t \le T_s$$

$$k_B(t) = -k_A(t)$$

k_i is the modulation index of the input side matrix converter.

Over a sub-cycle the average line to line voltage $V_{AB}(t)$ can be given as

$$V_{AB}(t) = \frac{3}{2} V_{in}[k_A(t) - k_B(t)]$$

Thus the square wave with amplitude $1.5V_{in}$ is the average line to line voltage to the transformer primary. The single phase high frequency pulsating voltage at transformer primary can be evaluated as,

$$V_{pri}(t) = \frac{6V_{in}}{\pi} \sum_{n=1,odd}^{\infty} \frac{1}{n} \sin(\frac{n\pi}{T_s} t)$$

where V_{in} the peak voltage of the three phase is input AC voltage source and F_s is the switching frequency. The average line current is in the transformer primary can also be a square wave. The input line current and the input voltage are in phase.

b)OUTPUT SIDE MATRIX CONVERTER

Matrix converter of output side, which is also a three phase to single phase matrix converters, the three phase AC voltage from a micro-grid source (DERs) to a high frequency single phase pulsating voltage at the secondary of the transformer. It is modulated in a same way as the input side matrix converter. Time varying signals $k_C(t)$ and $k_D(t)$ for output matrix converter are given by:

$$k_C(t) = +k_i \qquad t_p \leq t \leq T_s + t_p$$
$$= -k_i \qquad T_s + t_p \leq t \leq 2T_s + t_p$$
$$k_C(t) = -k_D(t)$$

Where k_i is modulation index and t_p phase-shift among the transformer primary and secondary voltage.

The single phase high frequency pulsating AC voltage at the secondary transformer voltage is given as:

$$V_{Sec}(t) = \frac{6V_{out}}{\pi} \sum_{n=1,odd}^{\infty} \frac{1}{n} \sin(\frac{n\pi}{T_s}(t - t_p))$$

Therefore the square wave with amplitude $\frac{3}{2}V_{in}$ and $\frac{3}{2}V_{out}$ is average line to line voltage respectively the transformer primary and secondary. Also the same as average line current are square waveforms. Thus scheme sinusoidal input voltage and line current is in same period.

III POWER FLOW CONTROL

Power flow control must be achieved such that it ensures reliability, affords financial system of function using finest production and uses minimum rate production. The power flow management by power electronics transformer is applied to a smart micro-grid, consisting of DERs powered by either renewable or non-renewable fuels. The smart micro-grid can operate smoothly by controlling the generating capacity as needed to match the load demand [5].

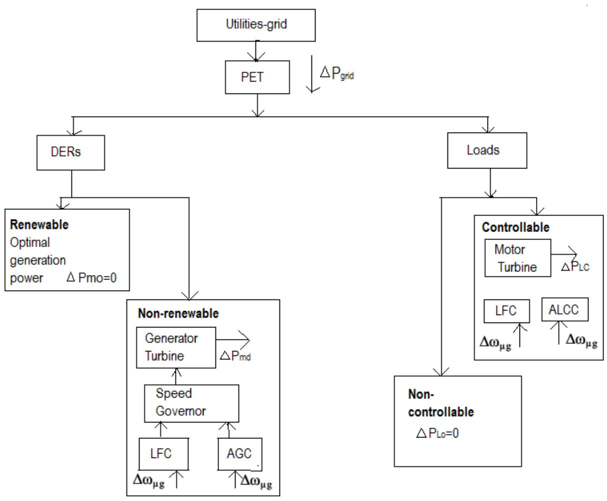

Fig.-4: Power flow control

Fig.- gives the parameters involved in the distinction of power flow at system height. The distributed generation inside the micro-grid present total mechanical power $P_{m,d} + P_{m,o}$ .where $P_{m,d}$ is the mechanical output power from G dispatchable distributed generation unit and the output from G_0 non-dispatchable $P_{m,o}$ .The non-dispatchable units (wind, solar cell etc) are assumed to operate at optimal conditions providing the maximum output generation and hence $\Delta Pm, o = 0$. So, valuable part of change in prime-mover $\Delta Pm, o$ for a micro-grid generated through the governor control. given as:

$$\Delta Pm, d = \sum_{k=1}^{G} \Delta Pmd, k$$
$$\Delta Pm = \Delta Pm, d + \Delta Pm, o$$

In the same way, the total load consumption is specified by $(P_{Lc} + P_{Lo})$. Where the total demand of load L controllable loads is P_{Lc} and the non controllable is P_{Lo}. For non-controllable loads the may or may not be critical P_{Lo} may experience a sudden disturbance changing the overall system demand. The entire load change ΔP_L maybe given as:

$$\Delta P_{Lc} = \sum_{k=1}^{L} \Delta P_{Lc,k}$$
$$\Delta P_L = \Delta P_{Lc} + \Delta P_{Lo}$$

The distributed generator units require to match the load demand inside the micro-grid and hence any change the load disorder or vary in grid supply, equation must be fulfilled.

$$\Delta P_L = \Delta P_m + \Delta P_{grid}$$

IV. SIMULATION RESULTS

The complete system is simulated on MATLAB/Simulink. The simulation study considers a micro-grid with only two DGs as shown in figure 5. Also it consists of both controllable and non-controllable loads.

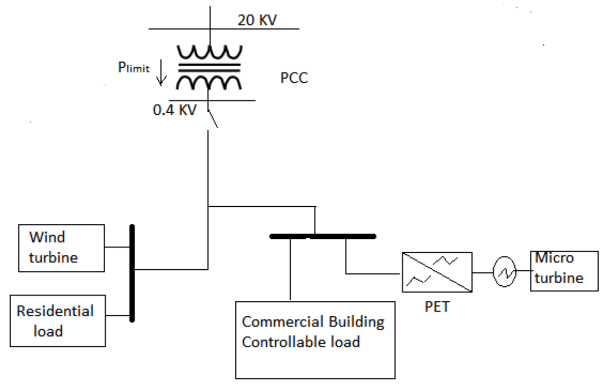

Fig-5: Model for simulation

The three phase micro-turbine is set with power electronics transformer. This unit can hence be provided with supplementary controls. The commercial building is assumed to have controllable loads but residential load cannot be controlled. Simulation result for different cases are studies as below :

CASE 1: Without controllable load only dispatchable DG units present in the micro-grid, a step vary in grid power increases the micro-grid production to balance the load demand within the micro-grid until frequency of the system is returned back to initial value.

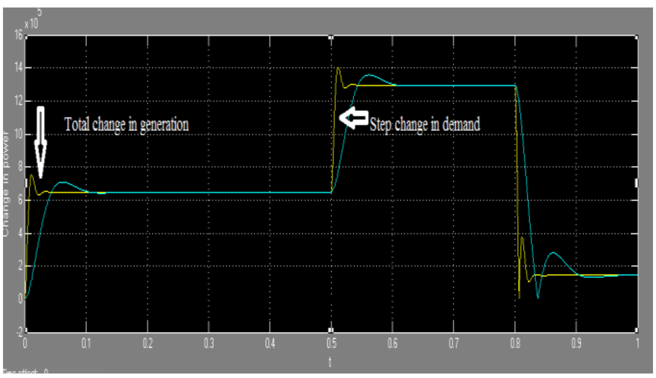

Fig:-6 Generation-Demand balance

CASE 2: Including controllable loads in the system with grid power change at instant t=0 results in initial reduction in power utilization when the system frequency drops and then the loads operate at initial conditions once the frequency is stabilized to the initial value. The DG units supply with the necessary change in power at steady state as shown in figure:

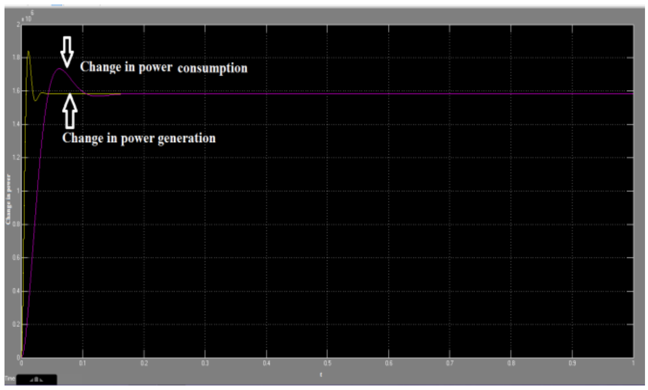

Fig:-7 Supply-demand balance

V.CONCLUSION

The power flow management for a smart micro-grid utilizing its grid frequency change as a control parameter is verified. The power electronics transformer proposed in this paper, active power flow from the grid can be controlled at the point of common coupling of a micro-grid to a desired value determined by the utilities. The strategy successfully enables us to achieve an extra degree of freedom due to presence due to the presence of active power control.

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